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Master's Thesis

Application of World Class Manufacturing to an automotive enterprise and integration with its quality management system

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To my family, my dears and Gianna

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1 Introduction

An Enterprise can present in every moment numerously issues and problems that have to be necessarily faced and solved in such a way that the objectives are respected. For this reason borns the requirement to create an opportune and valid method to reach this scope. This requirement culminates in the definition of activities provided by the World Class Manufacturing, namely a "way to think" well structured and defined that has as objective to achieve a continuous improvement of productive activity setting to zero the losses and wastes, with a solid base founded on the involvement of personnel, on choices and objectives shared at each level of hierarchical pyramid .

In the second chapter of this thesis is therefore introduced the World Class Manufacturing, starting from the American origins in 90's until its adoption and implementation in our country. So the principal features of the method are explained.

In the third chapter is introduced in its complex the structure of the method, which is characterized by ten technical pillars and an equal number of managerial pillars. In each technical pillar the activities are articulated in a subdivision of seven steps that have to be followed in order to realize each one of objectives prefixed, with the detection of issues and problems that have to be faced, and therefore the resolving activities that must be applied, ending with an improvement of approaches and structures used.

The fourth chapter consists in a short overview on the ATB S.p.a, on its history and structure, with particular attention to the Valperga plant, which is devoted to machining and assembly; here i spent part of my period of internship in the technical office, the "heart" of the plant. In particular, in the last paragraph of this chapter is discussed the route map of WCM of the enterprise. It allows understanding the changes occurred in the plant, clarifying what has done and what it is going to be done in order to obtain that improvement which is the goal of all methodology; therefore, it provides a vision of plant in the future and the direction followed to reach the fixed objectives.

In the fifth chapter the attention is moved to The Forno Canavese plant, which is devoted to forging; here i spent the larger part of my internship for the accomplishment of the main project assigned to me. In this chapter are discussed the main aspects of the forging technology and the steps of production of the raw parts and dies. Eventually, in the last part are introduced the main technologies adopted in the plant for dies design, forging and quality control of the raw parts produced.

Instead, the last chapter is focused on the main project entrusted to me during my experience in ATB, it was devoted to the reduction of the steel required for components production through the reduction of wastes due to the cut of the initial bars of steel. The activity was performed without affecting the standards of quality required by the clients, therefore, from this point of view it was actually a WCM activity.

2 The World Class Manufacturing method

2.1 The historical origins

The World Class Manufacturing (that is identified with the acronym WCM) is a method born in the USA in 90's and imported by FIAT in the year 2005, it was strongly wanted by the manager Sergio Marchionne.

This method is obtained from the convergence of three different approaches of production optimization:

1- Lean Production, which target is the minimization of wastes until their reduction to zero;
2- Total Productive Maintenance, which target is to cut down the plant losses;
3- Total Quality Management, which focus is producing well the first time;

2.1.1 Lean Production

Lean Production represents a "way to think" that establish its roots in the **Toyota Production System (TPS)**. This philosophy aim to minimizing the wastes until to reach the ideal result of zero. It considers a waste the expense of all resources that are not utilized for the generation of value for the client (added value). In other words the objective of Lean Production is the generation of product value trying to exploit the lower number of resources possible.

Taiichi Onho, vice president of Toyota Motors and father of Just in Time method, detects seven **sources of waste**:

1- *Overproduction*: more production with respect to what required by the client or by the subsequent process;
2- *Defects*: production of scraps of reworks;
3- *Excess of activity*: realization of activities that don't produce added value for the realized product;
4- *Movement* : displacements to reach materials and equipment far from the utilization point;
5- *Buffer stock*: purchase or production of materials in excess with respect to the requirement of successive process;
6- *Waiting time*: raw materials or semifinished products waiting to be processed, investment of time in an unproductive manner that could spent in other ways (other activities for example);
7- *Transport*: displacement of material or pieces without necessities connected to the creation of value;

The **benefits** that can be obtained through the application of Lean Production are :

- An increase of productive capacity;
- A reduction of production time;
- A reduction of inventory;
- A reduction of labor and fatique;
- A reduction of production costs and wastes;

The **planned activities** are seven:

1- Realization of a map of value;
2- Evaluation implementation state of most common techniques in the Lead methodology;
3- Training of operators and managers;
4- Pilot project;
5- Management of change;
6- Efficiency analysis;
7- Progressive elimination of activities that don't produce added value;

Closely connected to Lean Production is the **Just in Time method (JIT).**
It consists in the production of minimum quantities required to satisfy the demand of the client having buffer stock reduced at the minimum. It implies a passage from the logic "push" to the logic "pull".

- The ***"push"*** logic consists in producing a certain quantity of products decided previously on the base of data collected on the market, and on possible forecasts on the trend of demand. All the sequence of productive activities, starting from the supplying, occurs at priori from the arise of requirement. The execution of downstream activities is pushed by upstream activities.

- The ***"pull"*** logic consists in producing certain quantity of products on the base of requirement coming from the market. All the sequence of productive activities, starting from supplying, occurs at posteriori from the arise of requirement. The execution of downstream activities pulls the upstream activities.

2.1.2 Total Productive Maintenance

The Total Productive Maintenance (TPM) is identified as a productive system involved in the minimization of plant losses. Usually is (not correctly) considered as a simple procedure of maintenance, but it is different.

Seiichi Nakajima technical director of Toyota is considered the author of TPM, he edited it on the base of knowledge developed in USA about preventive maintenance, reliability, maintainability of plants and life cycle cost.

The principal objective of this system is to increase the performances and quality of plants. The field of application is concerned to instruments and machinery used to achieve the fixed level of quality or\and required by the client. It is useful to improve the efficiency of labor instruments, initiating preventive maintenance that is set on the base of criteria as: the importance of machine within the system, its age, the recommendations provided by supplier, the attention on operators and maintenance technicians.

It is based on five pillars:

1. *Cleaning;*
2. *Problem detection;*
3. *Correction;*
4. *Improvement;*
5. *protection;*

For what concerning *cleaning,* the basic maintenance of a machine is based on its daily cleaning, which is entrusted to same operators. Guaranteeing the basic conditions of machine are created the assumptions to guarantee an opportune utilization. A clean environment is index of care and allows the operator to feel himself comfortable, avoiding problems for the productive activity and also for safety. The cleaning is entrusted to operators and it does not require any particular training, what is important is an adequate behavior in the workplace. Performing a cleaning means also to have the possibility to perform a first inspection that can lead to the detection of problems that should be avoided (for example the operator can notice about the lack of a screw; he can notice about the malfunctioning of an optical sensor; the presence of oil on the ground and so on).

For what concerning *problem detection*, is provided a training course to the operator in such a way to be able to detect eventual problems on machine.

For what concerning *correction* the operator has to refer to the activities explained during the training.

For what concerning *improvement* are planned some activities in such a way to avoid the same problem again in the future (for example changing the maintenance criteria).Are created maintenance standards that have to be executed, on the base of problems faced previously and that can avoided.

Eventually for what concerning *protection,* the instruments and machinery are protected before, during and after utilization, according to instructions given by the supplier and\or experience, it allows to guarantee the execution of activities preventing the malfunctioning.

It is important to establish clear politics that can lead everyone to understand the fixed objectives. It is necessary to develop a strategy subdivided in annual strategy, middle time strategy and total strategy. Two very important aspects of this kind of system are the involvement and the level of morale of personnel. They have to be taken seriously by the manager. The improvement is determined by the people that are integral part of productive activity, which have to feel themselves motivated and trying to give an help that is fundamental for the enterprise. Therefore are formed some working groups, that can be volunteer or not, that are useful to solve the problems of operating type. If led with success, the TPM can increase rapidly the production associated to a production line, making at the same time the satisfaction of personnel higher. Therefore we shift from a maintenance performed only in case of failure, to a preventive maintenance. In this way once that the TPI program is activated, the uncontrolled arrest time due to emergency is reduced at the minimum. This kind of maintenance is performed periodically (monthly, weekly, daily) and is scheduled in such a way to keep the machines in the best functioning state possible to prevent failures. Moreover, it increases strongly the endurance of equipment and differently from the basic maintenance, it can be programmed in order to not coincide with the production time but with planned period of production arrest.

2.1.3 Total Quality Management

The Total Quality Management (TQM) is an organizational model which focuses its attention on "producing well already from the first time". The TQM is a managerial approach oriented on quality and based on the involvement of all members of an organization with the objective of achieving a long time success, through the client's satisfaction and benefits for the workers.

According to Japanese, the TQM is subdivided in four processes as follow:

1. *Kaizen,* which represents an instrument of continuous improvement;
2. *Atarimae Hinshitsu ,* according to which things have to work exactly as expected, it is focused on the optimization of processes;
3. *Kansei,* which through the analysis of modalities of utilization of a product, brings to the improvement of its features and functions;
4. *M.iryokuteki Hinshitsu,* which focus the attention on the design of the product, and how to make it nice and endearing.

The Total Quality Management imposes, to the enterprise that decides to adopt it, the maintenance of a quality standard in all its aspects. This means that all things are done well the first time and that defects and losses are gradually reduced until to zero

The characteristics of TQM are the following ones:

- A strong customer orientation, he becomes the person that must be satisfied and represents the motivation of approach application;
- A method based on long time commitment for the constant improvement of processes;
- A strong leadership of management, united to its involvement in the application of the method;
- The responsibility to establish and to improve the system is entrusted to the top manager, which has a fundamental role;
- The continuous improvement of performances at each level and area of enterprise,

The advantages derived from adoption of a system TQM instead of a traditional quality system are countless. Among these we can remind:

- TQM helps to stay focused on the requirements given by the market and perceived satisfaction, rather than technical details;
- It induces the desire to reach the top quality through a deep cultural change and team work promotion;
- This methodology makes natural orienting all the efforts to the common objective of best performance of all processes;
- The application of this method brings to examine all processes with a critical spirit in such a way to reduce wastes and activities that do not provide added value. This continuing effort towards the improvement helps to reduce costs, to improve safety and general management of work;
- The comparison of our enterprise with better ones , as is given by TQM, leads to the awareness of competition and elaboration of better strategies to face it;
- The TQM helps to develop a good communication: improper procedures and a bad communication originate misunderstandings, confusion, low productivity, big efforts to get low results, a low qualitative level and morale. Instead the application of this instrument, means to put into contact people belonging to different departments and levels of hierarchical pyramid, with the objective to make them commuticating in order to improve the general working approach.

2.2 The features

The **World Class Manufacturing** is a methodology which has as objective the progressive improvement of productive activity performed by the enterprise, through the modification of the plant, the modification of work modalities and the optimization of procedures with aim to reduce to zero wastes and losses.

The activities of all teams are oriented to the realization of projects which goals are: zero wastes, zero losses, zero defects, zero failures, zero incidents and zero buffer stock; for a general reduction of costs of plant.

The method's structure is composed by pillars, these latter are divided in ten technical pillars and ten managerial pillars (at the base of first ones) each one represented by a functional team that works on a specific topic.

Each pillar is based on seven steps, namely seven phases involving a series of activities that gives a contribute for the achievement of the principal objectives of the methodology.

The points of strength are:

- The **involvement** of people: it is very important that all members of different teams feel themselves as integral part of activities and in the center of problems that have to be faced. Each one has to feel himself capable to give an active support, collaborating with all colleagues for the achievement of a common scope, beneficial for the whole enterprise;

- The **increase of skills** of all organization: each member of the team, entering into contact with different problems, has the possibility of improving its skills from the technical point of view and absorbing the problem solving technics. All is a direct conseguence of methodology application;

- The **logic of prioritization:** is a very strong aspect, coming from a story of data analysis and losses of the plant. The enterprise will give the priority to all that projects that can really give a rapid and safe economic return, moreover will be managed the most critical aspects on the different fields (for example the machines are classified on the base of their criticity, and will be tried to improve those ones that are affected by the most important problems).

The step of each pillar are collected three **macro phases** that have to be performed in sequence: **reactive**, **preventive** and **proactive**:

Figure 2.1 *The macro phases of pillars activities*

The **reactive phase** is characterized by the capacity of react to an event, but not to foresee it in advance. Persons in charge have not the possibility to act in advance an action plan and can not try to control the cause of event: they can react only after that the event has already entered in collision with the enterprise system.

The **preventive phase** is represented by the possibility to take note of eventual past problems, on which is performed a study, bringing improvement and savings eliminating the deep causes of losses, in such a way to avoid that they can present again in the future.

The **proactive phase** involves the reorganization from the technological and methodological point of view, but especially from the point of view of skills, in such a way that the system can in advance understand the trends and future changes, in order to plan the proper actions in time.

The verification of plant performance level it is documented with a system of internal and external *audit,* they are adopted to evaluate the implementation of WCM with respect to the standards World Class. The *internal audit* are used as self-evaluation and are performed by the team of the pillar, instead the *external audit* are carried out by the *World Class Manufacturing Association.*

The *external audit* are usually performed annually and during these latter is evaluated the action of each pillar, at the end is assigned to each one a mark which goes from 0 to 5.

- "0" no activity in progress;
- "1" reactive approach;
- "2" basic technics performed;
- "3" good knowledge;
- "4" advanced level;
- "5" complete involvement.

The sum of all marks obtained from each pillar is equal to the *Methodology Implementation Index* (**MII**) which value ranges from 0 to 100, on the base of this index the WCM Association assigns a medal to reward and calssify the most prestigious plants in the implementation of the model, it represents a benchmark between the enterprises that decide to adopt the WCM model.

Figure 2.2 *The WCM medals*

3 The Pillars of World Class Manufacturing

3.1 The WCM temple

The WCM temple shows the pillars on which is based the whole methodology. It is possible to understand from the **figure 3.1** that it is structured in ten technical pillars (and ten managerial ones will be explained later).

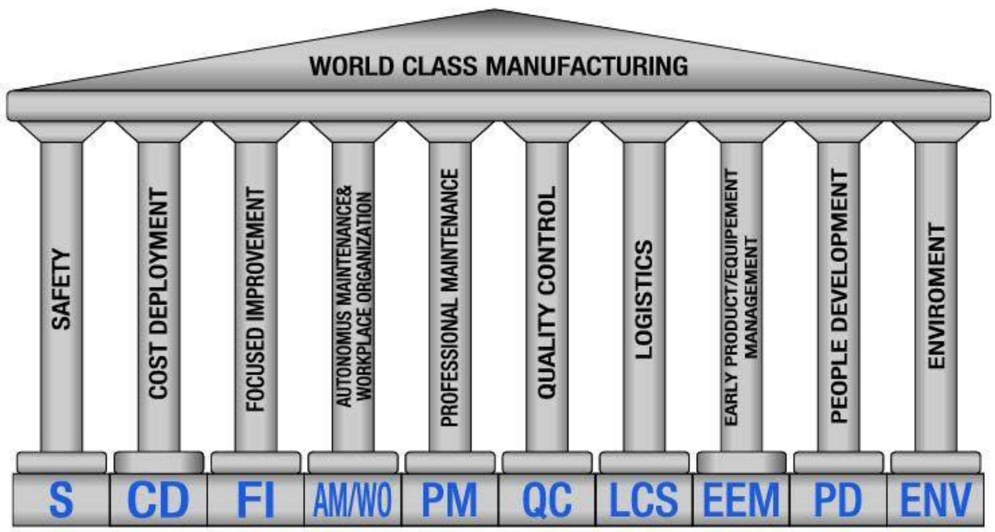

Figure 3.1 *The ten technical pillars of WCM temple*

3.2 The Technical Pillars

3.2.1 Safety

This pillar aims to satisfy the personnel needs, ensuring a continuous improvement of safety in the working environment with the objective of eliminating the conditions that could lead to incidents and accidents. These goals can be reached spreading the culture for safety at each level of the organization. The primary objectives of Safety Pillar are:

- The reduction of accidents;
- The development of a culture for prevention;
- The continuous improvement of workplace ergonomics;
- The development of specific professional skills.

Safety and health on the workplace are regulated by **D. Lgs. 81/2008** (known as the unique test about safety on the workplace, TUSL), entered into force the 15th May 2008; and by corrective dispositions, hence by D. Lgs. 106/2009. This decree, which had previous historical standards (as D. Lgs. 626/1194), transposes in Italy, the European directives (3rd August 2007, n. 123) about protection of safety and health of workers, coordinating them into a unique normative text which provide specific sanctions against defaulters.

The principal activities of Safety Pillar can be resumed as follow:

a. Analysis of events
b. Detection and evaluation of risks
c. Internal audit
d. Technical improvements on machines and workplace
e. Training and control

Progressively all people belonging to enterprise will have to be involved in a process of increasing sensitization about the normative, economical and ethical aspects.

Moreover the structure of Safety Pillar is founded on the following principal points:

- **Involvement of all the workers**: the success of system implementation depends on the awareness for each worker of responsabilities of own safety and that one of own collaborators.
- **Communication and Training**: The Safety borns from a right communication.
- **Skills**: The personnel must be adequately informed about dispositions given by the law and modalities of safe work.

For this Pillar are provided seven steps, preceded by Step 0 (preliminary activities) as reported on the **list 3.1** below.

The **reactive phase** includes Step 1, here are studied accidents and the causes that have originated them; the **preventive phase** includes Steps from 2 to 5, here are studied the countermeasures
to avoid that new accidents can present again and the personnel is properly trained in order to avoid behaviors that can bring to them; eventually the **proactive phase** includes the Steps from 6 to 7, it is characterized by safety standards and relative implementation.
It is possible to see the first four steps derives from Management initiatives, the fifth from individual initiatives and last two from team initiatives.

List 3.1 The steps of Safety pillar

STEP 0 → Preliminary activities that allow to fix le guidelines and priorities of action.

STEP 1 → Analysis of accidents and relative causes.

STEP 2 → Countermeasures and extensions in the similar areas.

STEP 3 → Initial standards of safety with the list of all problems.

STEP 4 → General inspection for safety with training of personnel.

STEP 5 → Autonomous inspection adopting preventive countermeasures against potential problems.

STEP 6 → Definition of autonomous standards of safety with total inspection of safety level.

STEP 7 → Implementation of system for management of safety.

3.2.2 Cost Deployment

One of the principal drawbacks of activities as TPM, TQC, JIT, and TIE is the lack of a direct link between the cost of these activities and their benefits in terms of costs reduction.

Therefore we realize that no system is satisfying if cannot propose an evaluation of costs. The traditional accounting systems have several weak points: often the Budget is defined on the base of previous year results without any logic analysis, hence the there is the risk of large differences from what declared by Budget; moreover often they does not put into evidence losses and wastes; it could not be a clear link between actions and results of the plant; they could lead to a not proper evaluation of costs generated by a low reliability of machines.

The Cost Deployment allows to overcome such limits, allowing to:

- detect the relations between cost factors, processes that generates costs and the different types of wastes and losses (for example machine failures, setup, defects, delays in materials supply);
- find relations between wastes, losses and their possible reductions;
- understand if the know-how is disposable for reduction of wastes and losses;
- classify the projects on the base of a Costs/Benefits analysis;
- make understand to people the total value of wastes and losses on their plants;
- generate savings;
- offer a guideline for the projects.

The principal objective of Cost Deployment methodology application is the reduction of losses and wastes in all the processes. Therefore let's define these two concepts:

A **waste** is the excessive use of input resources to get a certain output, hence basically a input quantity in excess (think about a glass full of water on which you continue to pour it).
A **loss** is the difference between the desired output and the one obtained, given a certain quantity of resources in input. A loss can be considered as an input used in a way that is ineffective (think about a glass of water with some holes from which water flow outside).

This pillar adopts a long series of matrices that are now presented:

- **Matrix A**: it allows the identification of wastes and losses within a process. In other words it creates a link between these two items and the relative process in which they are detected. It allows also to understand which are the most critical losses.

- **Matrix B:** It allows to distinguish the casual losses from resultant losses. Each loss has to be classified as "casual" or "resultant": a casual loss is a loss due to a problem of a process or equipment related to a certain process, while a resultant loss is a loss which derives from the loss of another process.

- **Matrix C:** It allows to translate the losses detected into costs. Starting from the matrix B are identified the causes giving origin to the losses related to the different processes, then these ones are transformed into costs through a proper cost structure. The data must be based on a temporal horizon of twelve months, and at first is necessary to consider the item of financial situation affected by each loss, and the tariffs for the translation into cost of the same. The value of each casual loss is its individual value plus le sum of the value of all resultant losses, each one computed independently and with a reference to the financial report.

The results can be reported and analyzed by resorting to the graphs of Pareto, which provide the possibility of stratifying the data in the most useful way to understand where is located the problem or simply to detect the most critical process.

- **Matrix D:** It allows to identify the methods to eliminate the most important losses (those ones generating higher costs). It shows a list of all the projects defined through the stratification of matrix C, and detects a method end a technical strategy to reduce to zero the loss attacked; this is the reason why it called also "Loss Matrix". The matrix D allows to set the principal pillar which is responsible of a casual loss reduction, together at the support pillars necessary to help the elimination of losses. There are two ways to attack losses: a "focused approach" and a "systematic approach". The first one attacks specific problem and achieves results in a short time; the second one is devoted to the solution of more general problems requiring more time but has a more extended impact. The phases of systematic approach are: identifying the attachable losses on the base of ICE index; choosing as attacking losses; evaluating the impact on KPI filling the matrix D. The ICE index undergoes the casual losses detected by matrix C to an evaluation of impacts, cost and easiness of attack.

  ICE = I x C x E

  - I (impact): it express with a ranking from 1 to 5 the economic value of detected loss.
  - C (cost): it express with a ranking from 1 to 5 the costs related to the improvement.
  - E (easiness): it express with a ranking from 1 to 5 the easiness (time and resources) in facing loss.

  Therefore ICE expresses with a ranking from 1 to 125 the possibility to attack a loss.

- **Matrix E:** It allows to estimate the costs for the improvement and possible reduction of costs. It is also called "Projects Matrix" since contains the list of all projects chosen to attack losses. The matrix E provides all the principal informations about each project, for example the quantity of losses attacked and the savings forecast, the area within which is verifying the project, the pillar involved in the project and so on; moreover it reports the value of each project of WCM improvement in terms of costs/benefits and impact on KPI. Therefore on the base of this matrix is possible to choose which initiative has to be considered before.

- **Matrix F:** It allows to set an improvement plan managing its implementation, it is a follow-up of results previously obtained with the matrix E. More than some key informations about the project, this matrix provides economic data for the monitoring of all plans of improvement.

- **Matrix G:** it provides a link between the financial budget and productivity coming from projects, in order to verify if the plan is improvable. This matrix is used to guarantee the existence of a plan to reach the productive objective for the next year.

Through the previously mentioned matrices is possible to perform the seven steps of the pillar:

Table 3.1 *The steps of Cost Deployment pillar*

STEP	**ACTIVITY**	**MATRIX**
1	Identify the total cost of transformation, Set a target of cost reduction,	
2	Identify qualitatively wastes and losses, Identify wastes and losses on the base of past data (if disposable) or on the base of previous measurings.	**A**
3	Separate casual losses from resultant ones.	**B**
4	Translate the losses and wastes indentified into costs.	**C**
5	Identify the method to recover wastes and losses.	**D**
6	Estimate costs of improvements and the relative losses and wastes reduction.	**E**
7	Arrange a plan of improvement and its implementation, follow up beginning from step 4, monitoring.	**F G**

3.2.3 Focused improvement

This Pillar consists in a focused approach for resolution of specific issues detected by mean of CD in order to achieve short-term results, with a large benefit in terms of reduction of costs due to wastes and losses. It is useful to reduce the most important losses present in the production system, to develop skills and know-how in the Problem Solving.
It looks for:

- an improvement of plan efficiency;
- set-up times reduction;
- reduction of wastes;
- professional growth and acquisition of the method;

Are introduced some indicators which are progressively improved, they are defined as **KPI** (*Key Performance Indicators*) and **KAI** (*Key Activity Indicators*).

The **KPI** (measure of productive performances) are:

- Efficiency;
- Productivity;
- Quality;
- Safety;
- Expected Savings.

The **KAI** (measure of efforts required to achieve an improvement objective) are:

- number of suggestions and Kaizen;
- number of used tools;
- creation of knowledge (For example OPL, acronym of one point lesson , hence illustrative papers which explain how executing an activity);
- definition of training needs.

The principal tool used by Focused Improvement for the solution of problems (elimination of causes) is the "**PDCA Cycle**".

- **Plan**: It consists in detecting the cause that has generated the problem, to analyze it and understanding the possible countermeasures to adopt.
- **Do**: It consists in the implementation of solution found in the previous phase
- **Check**: It consists in verifying the effectiveness of solution found and monitoring it.
- **Act**: It consists in the implementation of actual solutions, standardizing, improving, maintaining and if it is possible extending them.

Figure 3.2 *The PDCA cycle*

Here below **list 3.2** with the seven steps of Pillar **FI.**

List 3.2 *The seven steps of Focused Improvement pillar*

STEP 1 → Definition of important areas.

STEP 2 → Stratification of losses.

STEP 3 → Selection of issue to be faced.

STEP 4 → Selection of project team's members.

STEP 5 → Development of project (PDCA activity).

STEP 6 → Costs/Benefits Analysis.

STEP 7 → Follow-up and horizontal expansion.

3.2.4 Autonomous Maintenance & Workplace Organization

In this case we have as two Pillars united. The **Autonomous Maintenance** is represented by all activities carried out by the machine operator in an independent way in order to eliminate the condition of decay, maintain the machine in basic conditions, maximize the system effectiveness and maintain the "Zero Breakdown" condition. Are included in these activities: inspections, cleanings, controls, substitutions, disassembly, small repairs; hence everything that allows to prevent failures or machine stops that can be solved only by the Professional Maintenance Pillar.

Thanks to an important factor of operator involvement, this one can increment the knowledge of environment and machine with whom is continuously in contact. Therefore, the Autonomous Maintenance is involved in the increment of global efficiency of plants and products quality, improvement of machines life through the involvement and collaboration of personnel.

Follow the **list 3.3** with the seven steps of **AM:**

List 3.3 *Steps of Autonomous Maintenance pillar*

STEP 0 → Preliminary activities.

STEP 1 → Initial cleaning and inspection.

STEP 2 → Elimination of dirt sources and areas to clean of difficult access.

STEP 3 → Creation of standards for cleaning and lubrication.

STEP 4 → General inspection.

STEP 5 → Autonomous inspection.

STEP 6 → Improvement of standards.

STEP 7 → Program of Autonomous Maintenance totally implemented.

The second part of AM is **Workplace Organization**. It is concerned to the workstation organization (technical criteria, methods and instruments) in order to improve the productive activity and environment for the operator. The principal objective of this Pillar is the increment of productivity in the areas of intensive work, keeping present and respecting the concept of Minimal Material Handling, where this latter represents the research in avoiding or minimizing the humans and materials displacements.

The activities involved bring also to:

- improve the workstation ergonomics;
- guarantee the personnel safety;
- correct supplying of materials;
- standardization of all operations.

This pillar goes to attack one of principal losses detectable in a plant, hence the Non Added Value. Therefore let's do a distinction between **Added Value, Semi Added Value and Non Added Value.**

The Added Value is the time necessary to carry out all those activities which transform and add value to the product (assembly for example).
Semi Added Value is the time required to carry out all those activities that are necessary to the progress of Added Value activities, and that do not add value to the product (for example the loading/unloading activity of pieces from machine, activity that does not directly transform the product but that is necessary for the piece processing).
The **Non Added Value** is the time necessary to execute all those activities that does not transform and add value to the product (for example the displacement performed by the operator to get the raw materials).

It is obvious to understand that all those activities that does not increase the value of the product represent activities that have to be limited as much as possible, since this time can be converted into other activities that can increase the value of the product, but also because are activities that are not paid by the customer ,since not included in the effective value of the final product.

The preliminary activity of the pillar involves the application of Five S Method:

- Seiri: separating what is useful from what is not;
- Seiton: arranging space and instrument;
- Seiso: cleaning;
- Seiketsu: standardization of previous operations;
- Shitsuke: diffusion of cleaning and order discipline.

Then it is possible to proceed with the creation of first standard by mean of Three M Method, it consists in the elimination of:

- Muri: movements and operations that are not ergonomics;
- Muda: non standard operations;
- Muda: Non Added Value activities.

The Workplace Organization uses particular instruments as **OPL** and **SOP**.
OPL is the acronym of One Point Lesson, it is represented by an illustrative paper which has the objective of consolidating the training and skills, focusing the attention on a single problem that has to be accomplished in short time. It must be formed for the 80% of pictures and has to be clear and understandable.

SOP is the acronym of Standard Operation Procedure, it is represented by one or a series of illustrative papers that have the objective of making the operator capable to carry out the activity described. As the OPL it must formed for the 80% by pictures and has to be clear and intuitive to be understood by all.

Here below are reported the seven steps of **WO** in the **list 3.3**

List 3.4 S*teps of Workplace Organization pillar*

STEP 1 → Preliminary cleaning.

STEP 2 → Arranging of the process.

STEP 3 → Definition of cleaning standards.

STEP 4 → Training on product characteristics and general inspection on tools and instruments.

STEP 5 → Just in Time supplying of material.

STEP 6 → Improvement of initial standards.

STEP 7 → Implementation of standard work sequences.

3.2.5 Professional Maintenance

This pillar it is aimed to prevent eventual breakdowns than can occur during the productive activity, involving a maintenance system that can extend the life of machine's components.

The objectives of this pillar are:

- Maximizing the effectiveness of machines and productive lines, where for effectiveness we mean the capacity to reach a determined objective, in this case it goes to protect plant from eventual breakdowns.

- Maximizing the reliability and disposability of machines (taking into account the costs) going to make these ones always ready to work.

- Eliminating the activities of extraordinary maintenance, which lead to extra costs (sometimes is required the action of external personnel) and cause a machine stop subtracting time to other productive activities.

- Reaching the **ZERO failure** of plants (breakdowns, short stops, defects and so on) with the collaboration of production operators.

Therefore it aims to null the presence of breakdowns preventing them, with the possibility of using maintenance techniques that are able to elongate the life of components, hence of machines too.

There are different types of maintenance:

- Breakdown maintenance
- Periodic/cyclic maintenance
- Predictive maintenance
- Corrective maintenance

The **Breakdown maintenance** implies the intervention only after the breakdown has occurred. This kind of maintenance can be chosen for those components belonging to a machine that has not stops, or the cost for their preventive maintenance is higher than losses due to the stop (but the impact in terms of safety must be null). On one hand there are the advantages of having low costs, of not having the necessity of action plans but only requiring the disposability of replacement parts, to require only limited skills of diagnostics and maintenance. On the other hand there are the disadvantages of not having early advices about failures (this implies a risk for safety), of having uncontrolled production losses and requiring a lot of people disposable for maintenance.

The **Periodic/cyclic maintenance** works periodically on the machine according to maintenance cycles with a frequency based on time or utilization, in such a way to prevent failures or stops. This kind of maintenance can be applied if its cost is lower than the cost of failure. Moreover all the activities are performed on the base of production stops (the lunch break for example) in order to reduce at the minimum the number of scheduled arrests. On one hand we get the reduction of failures and a more effective utilization of labor. On the other hand the component it is not exploited completely until the end of its life, therefore the maintenance could be actually not necessary.

The **Predictive maintenance** is based on the fact that the larger number of failures do not occur suddenly, but it is possible to detect some signals which are precursors of failure (for example the whistle which is hearable when the bearing is at the end of its life). In this case is possible to plan the maintenance activity on the base of actual life of machine and not on the base of statistical data. On one hand it improves the exploitation of components, moreover some form of inspection which adopt the five sights are not expensive and are also very simple, eventually it allows to stop the activity before that failures causing heavy damages can occur. On the other hand vibration analysis, thermography and oil analysis requires skills and specific instruments, all techniques must be chosen properly, it is required time to build a trend and create a link between the structure conditions and possible kind of failures.

The **Corrective maintenance** involves all those modifications which allow to increase the maintenance capability and reliability of machines. It can be meant as a combination of Breakdown maintenance and Periodic/cyclic maintenance, more specifically it is not actually a kind of maintenance but an approach that has to be followed during maintenance activities in such a way to improve the machine itself. To be properly applied it is required always to compute costs/benefits ratio before improvement; moreover it involves the preparation of equipment, instruments and replacement components for all activities. On one hand the modifications of equipment can be cheap and functional and a serious problem can be solved at its root. On the other hand the actual cause of the problem could be misunderstood, some modifications proposed could be expensive, requiring times of arrest too long to be implemented, unexpected events could take place because of changes and the solution of a problem in a determined area could cause the overload in another one

The seven steps of Professional Maintenance are reported on the **list 3.5** here below:

List 3.5 *Steps of Professional Maintenance pillar*

STEP 0 → Preliminary activities.

STEP 1 → Elimination of forced degradation and prevention of accelerated degradation.

STEP 2 → Failure analysis.

STEP 3 → Definition of Maintenance Standards.

STEP 4 → Countermeasures on weak points of machine and increase of components average life.

STEP 5 → Building of a Periodic Maintenance system.

STEP 6 → Building of a Predictive Maintenance system.

STEP 7 → Maintenance costs management and building of Improved Maintenance system.

3.2.6 Quality Control

The Quality Control principally is aimed to reach the complete satisfaction of the client through the quality excellence. From this point of view it borns from the need to reduce at the minimum the defects signaled by the customer and represents a real guarantee for the retention with it. In practice it aims to actuate all those actions which define and keep under control the desired standard of quality. Obviously the activity of quality control is an activity which does not give an additional value to the product, but it is fundamental for the detection of problems and defects which brings to losses for the enterprise, therefore allowing to understand the causes that generate the unconformity of a part. In particular the problems detected can be classified on the base of their own cause according to the Logic of Four M, hence “Man”, “Method”, “Material” and “Machine”.

The objectives of the pillar are:

- to define the conditions to get **ZERO defects**;
- to generate the operative standards to maintain these conditions, passing from a reactive approach (adoption of the countermeasures when a problem has verified), to a preventive approach (preventing the problems before they can occur);
- to improve the personnel skills in order to solve and preventing the quality problems;
- reduction of losses due to low quality level.

The seven steps of Quality Control are reported in the **list 3.6** here below:

List 3.5 S*teps of Quality Control pillar*

STEP 1→ Investigation about the actual conditions.

STEP 2→ Improvement and restoration of operative standards.

STEP 3→ Analysis of loss factors.

STEP 4→ Reduction and removal of all causes of loss.

STEP 5 → Detection of proper conditions to get zero defects.

STEP 6→ Keeping of proper conditions to get zero defects.

STEP 7→ Improvement of methods adopted to keep the conditions to get zero defects.

3.2.7 Logistics & Customer Service

This pillar has the assignment to synchronize the production with requirements given by the client, in order to satisfy completely and with precisions the needs of this latter.

This has to be done trying to minimize as much as possible all the costs correlated to management and transport of materials. Other principal objectives are minimizing the inventory (warehouse stocks have a cost and are affected by a risk of damage and aging) creating a continuing flux, and minimizing the lead time, where the lead time is the interval of time required by an enterprise to satisfy the client demand, more this time is low, more the enterprise is fast. Therefore is necessary to cut the lead time in order to produce only what is necessary, when it is needed and in the quantity required. To accomplish this, the following passages have to be considered:

- to analyze accurately the client demand;
- to pass from a "make to stock" concept to a "make to order" one;
- to have a productive system extremely flexible;
- to buy the material only when required (JIT);
- to have sales, distribution, production and purchases all integrated.

The seven steps of Quality Control are listed on the **list 3.6** here below:

List 3.6 S*teps of Logistics & Customer Service pillar*

STEP 1 → Redesign the lines to satisfy the client.

STEP 2 → Plan of the internal logistic.

STEP 3 → Plan of the external logistic.

STEP 4 → Levelling production.

STEP 5 → Improvement of external and internal logistic.

STEP 6 → Integration of sales, production and purchases network.

STEP 7 → Adoption of a sequence programming.

3.2.8 Early Product & Equipment Management

The Early Equipment Management is aimed to make the plant advanced and competitive keeping to improve it continuously going to anticipate eventual problems which can born during production activity. This is possible designing machines and equipment considering all the problems detected on the ones previously used and that now are going to be replaced. The pillar is therefore involved in providing new machines and equipment to the plant through a close collaboration between designers and suppliers, in such a way to improve quality, reliability and *Life Cycle Cost* of machinery.

For what concerning the Early Product Management is valid the same concept of Early Equipment Management, but extended to new products introduced. Here is again required a close collaboration between designers and suppliers in order to introduce quickly new products in the production process, engineering products and processes.

Therefore the pillar goes to face all the problems which can born in a plant as production defects, production difficulties, maintenance difficulties, lack of skills and knowledge. All these ones can induce costs which can be avoided improving machines, equipment and the product itself.

The seven steps of the pillar are reported on the **list 3.7** here below:

List 3.7 S*teps of Early Product & Equipment Management pillar*

STEP 1 → Investigation on investments efficiency, machines and equipment planning.

STEP 2 → Estimation of costs related to machines, equipment and times.

STEP 3 → Development of the project through MP design, equipment FMEA and process FMEA.

STEP 4 → Intermediate check of the project, check of the budget and deadlines, maintenance training.

STEP 5 → Machines installation, check of positioning and lay-out, check of installation; installation of auxiliary plants, pipes and cables; personnel training.

STEP 6 → Check of capacity and performances, detection of problems about reliability, operability, maintainability and safety.

STEP 7 → Initial flow control.

3.2.9 People Development

The success of WCM methodology is clearly based on the capacity and knowledge of people that apply it. Therefore, the People Development has a fundamental role to reach the objectives prefixed by the methodology: principally it involves the personnel training, in such a way to achieve a correct and effective application of WCM in the various fields.

The training has to be prioritized on the base of:

- safety problems;
- quality problems;
- losses and wastes;
- failures;
- stops;
- human errors.

All these errors are often linked to a lack of skills and resources at various levels of hierarchical pyramid, on the base of them training has to be planned, and the operative results have to be evaluated; for this purpose are adopted different approaches as **TWTTP**, **HERCA** and the **Luti's method.**

The **TWTTP** (The Way To Teach People) is an interview done to the person who generated the error. A wrong answer to the demands proposed put into evidence a lack of skills and knowledge; when the interviewed gives one or more wrong answers, training is necessary as countermeasure. When all the answers are correct means that the cause is not a lack of knowledge, therefore this means that HERCA is required to investigate on the possible other causes that generated the problem.

HERCA (Human Error Cause Analysis) consists in the monitoring of the person while he is executing his job, in such a way to put into evidence one of the other possible causes which generated a certain problem. Some examples can be represented by: incorrect behavior, organization capacity, technical problems and forgetfulness; for each cause obviously a proper countermeasure exists.

The **Luti's method** is made of four phases: Learn, Use (consists in applying in the plant what learnt during the previous phase, evaluating the results given by application, writing all in order to create the know-how to be transferred); Teach (consists in teaching to other components what learnt and written) and Inspect (consists in evaluating the effectiveness of what teached).

The seven steps of the pillar are reported on the **list 3.8** here below:

List 3.8 S*teps of People Development pillar*

STEP 1 → Definition of principles and priorities of training system.

STEP 2 → Definition of an initial training system for the development of skills.

STEP 3 → Development of a system to improve skills of team.

STEP 4 → Definition of a consistent training system for the development of skills.

STEP 5 → Development of system for the growth and enforcement of more advanced skills.

STEP 6 → Development of specific skills.

STEP 7 → Continuous assessment finalized to the enterprise and individual success.

3.2.10 Enviroment

This pillar is involved in the development, actuation and maintenance of programs for environmental protection; in particular according to it resources are used in order to reduce energetic consumption and pollution following the guidelines provided by normative ISO 14000.

The seven steps of the pillar are reported on the **list 3.9** here below:

List 3.9 S*teps of Enviroment pillar*

STEP 1 → Understanding of environmental rules.

STEP 2 → Prevention of contaminations.

STEP 3 → Preparation of provisional standards.

STEP 4 → Energetic and resources savings, chemicals control.

STEP 5 → Foundation of an environmental management system.

STEP 6 → Creation of a system to reduce the environmental impact.

STEP 7 → Utilization of the environmental management system to create a model plant

3.3 The Managerial Pillars

The managerial pillars (at the base of technical ones) have been introduced in order to carry out a supporting activity to the technical ones. The number of these pillars is the same of technical ones (10) and are realized again through 7 steps, they put into evidence the importance of elements as planning capacity, organization, leadership and motivation. Those elements allow to overcome the limit of Lean Production which does not involves these factors, providing an help to the application of methods concerning technical pillars. Therefore let’s do a brief overview on these pillars.

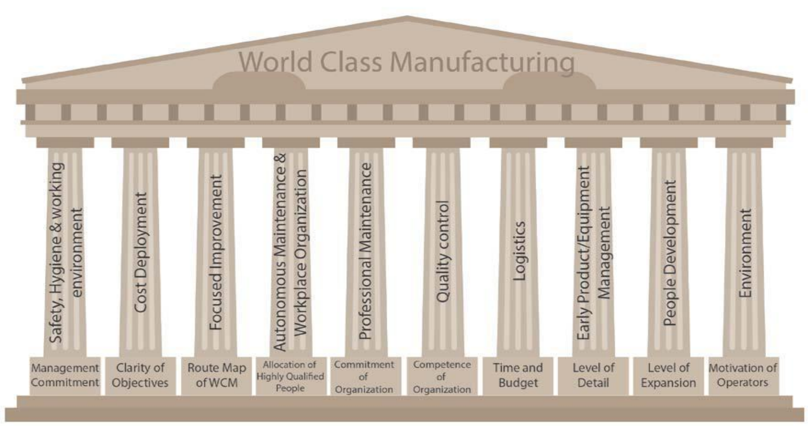

Figure 3.3 *The ten managerial pillars of WCM temple*

3.3.1 Management Commitment

It represents the presupposition from which is necessary to start to operate a certain revolution in the proper fields, and it is fundamental to ensure that all the personnel can metabolize the change; it can be divided into different activities performed by management:

- transforming the strategic objectives into operative ones: hence passing from the theory to practice, from the general aspects we pass to specific plans which are going to be applied to the personnel;
- delegating activities: with delegation is possible to pass power from an higher level of hierarchical pyramid to a lower one, allowing an involvement and an importance sense beneficial for the personnel involved;
- directing transversal meetings: it is important a frequent comparison between management and operative personnel in such a way that the activities performed by these latter reflect perfectly what designed strategically, it is possible for example a comparison between daily production and planned one.

3.3.2 Clarity of Objectives

This pillar is involved in the definition of objectives having the following features:

- *clearness*: it is important that the information are interpreted in the correct way to avoid misunderstandings;
- *quantification*: the objectives have to be always expressed in quantitative terms and never qualitatively;
- *spread*: all people involved have to know the fixed objectives and have to feel themselves involved too.

By mean of activity performed by Cost Deployment is possible to detect the most critical areas in terms of losses for each pillar, therefore is possible to fix all the objectives to null these latters (and wastes) translating them in terms of KPI (Key Performance Indicator).

Subsequently, it is necessary to do a comparison between the actual trend of KPI and those expected during the phase of realization of the project; all the informations have to be provided both to management and involved personnel, in this way everybody can understand the effectiveness of work performed.
If the trend is not aligned with what expected by project, then is necessary to adopt some corrective actions in such a way to come back again on right direction; differently, if the trend is aligned according to what expected, all the people involved will receive a positive confirm of the work carried out, they will feel themselves realized and repaid of their efforts.

To inform all the people involved about the developments of the projects, usually it is set a corner in the plant, on which are exhibited:

- The objectives targeted by the projects;

- The actual trend of the different KPI associated.

3.3.3 Route Map of WCM

It consists in a map of the plant on which is explained the transformation of this latter on the short, average and long term time horizon; in this way it allows to understand the changes occurred in the plant, clarifying what has done and what it is going to be done in order to obtain that improvement which is the goal of all methodology; it provides therefore a vision of plant in the future and direction followed to reach the fixed objectives.

This map is realized taking into account two important factors: what is expected by the client (the satisfaction of the client is a fundamental element of the whole methodology that we can find in the various fields) and the vision of the enterprise.

From the general route map of the plant is possible to pass to the single route maps related to each pillar, from this point of view is important to take into account two aspects: managerial and technical pillars have to work in parallel along the same direction, approach and behavior have to be the same for both the kind of pillar.

For what concerning the first point we have to notice that there are numerous interconnections between the pillars belonging to the two different fields; this means that what is done in one of the two, automatically it is reflected on the connected pillar; in other words, in a plant is impossible to get an high score for the technical pillars, and at the same time, a low one for the managerial pillars. This concept is again underlined in the second point in terms of behavior; therefore we are talking about an “internal balance”, a fundamental element for the reaching of all pillar’s objectives.

The Route map of the plant it is shared with all the personnel of the plant; in this way everyone can understand what is expected for the future, the activities are more clear since allocated on a clear path, and knowing the objective the personnel can get the right motivation to act on that direction.

3.3.4 Allocation of Highly Qualified People to Model Areas

A fundamental aspect of WCM is the training of the personnel and its involvement in the projects of improving.

The personnel involved in the production activities have to learn the fundamental informations concerning these latters to get the improvement, from this point of view borns the necessity to exploit the experience of skilled and qualified operators allocated in the model areas, to teach how a determined operation has to be performed, in this way the knowledge is transferred to who actually will carry out the activity. The goal is obtaining a sort of self-management of the structure, in such a way that the personnel can perform correctly all the activities, and that can detect and manage with autonomy eventual problems to be faced.

Within this vision the leader of the pillar has to carry out continuing control of performance, and to evaluate its consistence with the route map.

The pillar is based on three fundamental elements:

- *KPI*: performance indicators which allow to understand qualitatively and quantitatively the achievement of a goal, they give a measure o results obtained;
- *methods and instruments:* every time must adopted the most proper technics and instruments in the correct way*;*
- *staff growth*: the manager responsible of the pillar has to promote the cultural growth of all members of the staff, and to verify the progress in terms of achieved capacities.

3.3.5 Commitment of the Organization

We discussed about the pillar of Management Commitment, but the efforts of Management are not enough to achieve the objectives prefixed, the whole organization at the different levels of hierarchical pyramid has to be involved with the same spirit. Despite this, often some components of the personnel do not recognize to have problems or do not make anything to face them; this attitude cannot be accepted by an enterprise that want to become World Class, all the problems must be detected and faced in the most proper way.

The activities of the pillar can be resumed as follow:

- the staff has to face the problems related to the activity performed exploiting the resources disposable, trying to keep a positive attitude;
- the projects have to be developed through the collaboration of the whole organization at different levels of hierarchical pyramid;
- once that an objected is achieved, the leader of the pillar has to keep to work on improvement of the method and resources exploited;
- the delegation process from management to pillar's teams has to become always more effective and quick in terms of response.

3.3.6 Competence of Organization toward improvement

As already said the principal objective of WCM is to reduce wastes and losses until to null them (if it is possible); from this point of view, the methodology exploits different methods/tools, that if applied in the correct way brings to the solution of the problem through the elimination of causes which generated it. For problems that are not too complex is adopted the "Quick Kaizen" tool, with a fast and specific action; while in the case of more complex problems it is possible to adopt "Standard Kaizen", "Major Kaizen" and "Advanced Kaizen" tools depending on difficulty related to problem solution.

The procedure involves the creation of a database containing all the informations concerning a certain problem, informations concerning the method, times and inherent costs; in this way all material necessary to the problem solver, to get a complete vision of the object is provided.

All these data are collected and arranged providing the guidelines to be interpreted correctly, in order to avoid possible misunderstandings, in other words this pillar is involved in the provision of all the necessary to face and solve a problem.

3.3.7 Time and Budget

Usually the WCM projects has an endurance in between the three and fourth months , therefore time an budget have to be specified, to understand how many and the kind of resources are required for a certain project, they are two central factors of the whole methodology.

The time required for definition and realization of a project depends on the problem faced, it is clear that this parameter has to be reduced as much as possible in such a way that the problem can be solved as soon as possible, giving the possibility to continue to carry out a certain activity without any obstacle.

From this point of view must be added that accelerating the times required to solve a certain problem, it is possible to concentrate the efforts towards other projects always considering the direction of improvement.

The other very important factor is budget, with budget we mean all the financial resources disposable, and it represent the source from which is possible to draw in order to cover all the structure of costs. Budget is strictly linked to the concept of efficiency, where the efficiency it is meant as the capacity to achieve a goal with the minimum exploitation of resources given by the Management, therefore each project is defined according to a certain budget within which the economic efforts have to enter.

3.3.8 Level of detail

The level of detail represents a scale of specificity with which a problem is faced. More a problem is deeply analyzed, more is possible to get closer to what originated it, going to eliminate the cause definitively. This pillar is therefore aimed to eliminate the causes of losses resorting to actions as specific as possible, the following benefits can be obtained:

- detecting and understanding the root of a problem or phenomenon;
- eliminating most complex problems;
- obtaining the level of efficiency as higher as possible, hence achieving the objective with the minimum utilization of resources;
- detecting the root of a problem and eliminating it by mean of tools disposable, making possible to avoid it in the future or having the knowledge to solve it again.

3.3.9 Level of Expansion

This pillar is involved in all the activities concerning the expansion of improvement related to a determined area to the other areas of the plant, by mean of this expansion is possible to get the excellence.

All begin from the moment when the Cost Deployment goes to classify the operations according to a logic of priority based on costs, passing from a class AA to class C through the classes A and B; according to this classification each pillar starts the operations on the model area, until to involve all the plant.

The maximum ambition of this pillar is to extend its radius of action beyond the plant and enterprise in general, therefore involving in the improvement also suppliers.

3.3.10 Motivation of Operators

The whole methodology is funded on people implementing it, from this point of view borns the necessity of a particular involvement of all operators because they perform the productive activities, they have to feel themselves an integrating part of a system, positioning this ones at the center of the project.

The verification of involvement status is done by mean of three factors: “number of suggestions”, “number of Quick Kaizen” realized and the “absenteeism rate”. Each member of the personnel, being part of the productive activity can give indications concerning to how could be possible to introduce improvements beneficial for the enterprise system, improvement is in fact a central question of whole methodology.

Kaizen is given by composition of two Japanese terms: “kai” and “zen”, first one means “improvement” while second one “best”, and the operator is the first element responsible of improvement.

The absenteeism rate is index of operators reliability: a little absenteeist operator is probably a person which is motivated to carry out his work and that feel himself motivated on its workplace.

Coming back to operator involvement, as already said on Clarity of Objectives pillar, is fundamental that he knows exactly which are all objectives and that is informed about the results achieved by projects, this can bring to a double beneficial effect:

- If the results are positive, the operator will be probably gratified by his work, this is important to keep his mood high, therefore also for the next projects in the future;
- if the results are negative, it is fundamental to bring back the project on right direction, but before it is necessary to detect the causes of errors, in this sense the involvement of operators is very important, since they know specifically the productive processes and related problems.

Eventually, to get a high level of involvement, Management has to make feel the operators important and at the center of organization, considering theme as a principal element to achieve the excellence.

3.3.11 The most important aspects of Managerial Pillars

After this brief overview on managerial pillars, here are listed their fundamental aspects, resumed as:

- *change of mentality;*
- *accountability;*
- *motivation;*
- *consciousness.*

For what concerning the change of mentality: the whole methodology is result of a different way to think; the change is therefore necessary to detect, face and solve all the possible problems.

For what concerning accountability: it is fundamental to motivate the operators, through a responsibility feeling the personnel feel itself involved and this brings automatically to the commitment of each member of the organization.

A motivated operator is more prone to the achievement of prefixed objectives, this element is obtained though the delegation mechanism, starting from the highest until to lowest level of hierarchical pyramid.

Eventually for what concerning consciousness: is important that everyone has well in mind which are the final goals, either specific as general, and that is conscious of what he is doing. Having clear the starting point and the direction to follow, is possible to walk on the right path.

4 ATB S.p.A.

4.1 A short introduction and history

ATB S.p.A. was founded in 1891 experiencing the entire evolution of production and technological systems during its history, both in steel hot forging and in parts machining. Two main strategic objectives have driven growth and development of the company in the last twenty years: quality and components added value.

Benevenuta Argentina (Cordoba) was born in 1996 as a manufacturer of shift forks for passenger cars transmissions. New processes were then introduced and today the product range includes shift rails, shift lugs and complete subassemblies for car and truck transmissions. Manufacturing processes see the use of CNC machining centers and transfers, broaching and grinding machines, injection molding, induction hardening and laser welding.

A.Benevenuta & C. S.p.A. (Italy) produces components made of hot-forged steel with mechanical presses; they can be supplied in finish machined condition, with possible assembly. The parts can be completed with other surface treatments or coatings (according to customer drawings) which are performed by suppliers managed by the company. ATB S.p.A produces parts designed by its customers and does not develop its own products, some examples are reported in **figure 4.1**.

The manufacturing plants are:

- **Forno Canavese**, devoted to **forging** with mechanical presses (manual and robotized) 1200 T - 1300 T - 1600 T - 2500 T.
- **Valperga**, devoted to **Machining & Assembly** with Horizontal and vertical CNC machining centers

The forging tools (dies) are developed and manufactured in the toolmaking department of Forno plant. The company has invested in technological innovation and has implemented automated machining, welding and laser hardening processes. CAD-CAM and simulation systems are able to help with design, study, prototyping and manufacturing of the required components, based on customer's needs.

__Figure 4.1__ Examples of mechanical parts produced for different classes of vehicles

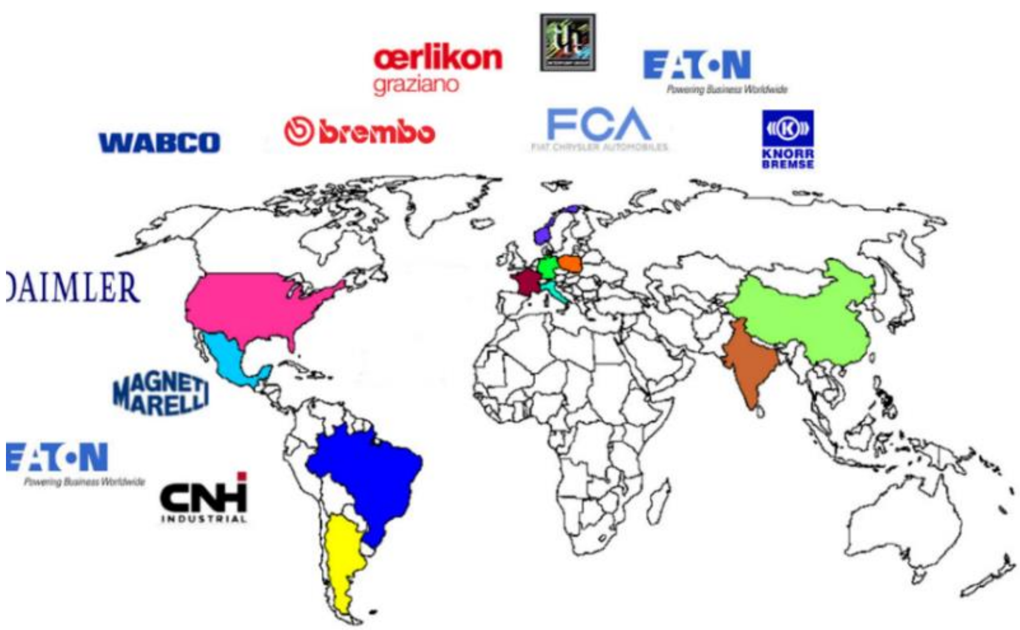

__Figure 4.2__ Map of the clients

4.2 Valperga plant: machining and assembly

The plant is devoted to Machining & Assembly of raw parts coming from the site of Forno Canavese, machining processes are performed with Horizontal and vertical CNC machining centers; the **figure 4.3** and **4.4** are referred to the inside of the plant: from the two pictures it is visibly possible to understand the impact of WCM methodology application: the level of cleanness, order and organization reflects the spirit of the method, these features allow to increase remarkably the safety of personnel in the workplace, and to reduce wastes in terms of handling time.

Figure 4.3

Figure 4.4

In particular, each day the raw parts to process are transported in correspondence of the picking area, the quantities are specified on kanbans on the base of production schedule; this area is located immediately in proximity of CNC machines, therefore the operator can immediately find the lot to process here, avoiding the movement of material from the warehouse to the center. A schematic representation of raw parts flux (arrows) from the picking area to centers is given in **figure 4.5** here below:

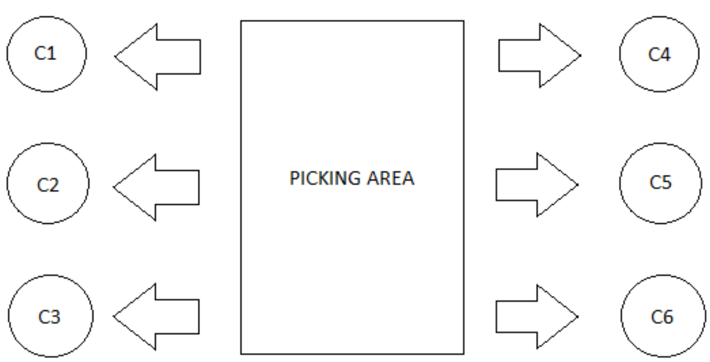

Figure 4.5

The technical office is the heart of the plant, here by mean of 3D design softwares:

- It is studied the configuration of raw parts to process within the CNC center, in such a way to optimize spaces and machining time;
- It is designed the equipment to keep in stable position the raw parts during machining process (the tool);
- are studied the machining cycles and the optimal tool path in such a way to reduce wear, avoid useless movements and dangerous tool/part collisions;
- it is evaluated which kind of tool is more suitable (standard or customized) to perform the machining processes required.

Once that the design of equipment is completed, the tool is assembled in the toolmaking department, eventually it is tested on CNC center executing some proof cycles in order to evaluate some eventual improvements.

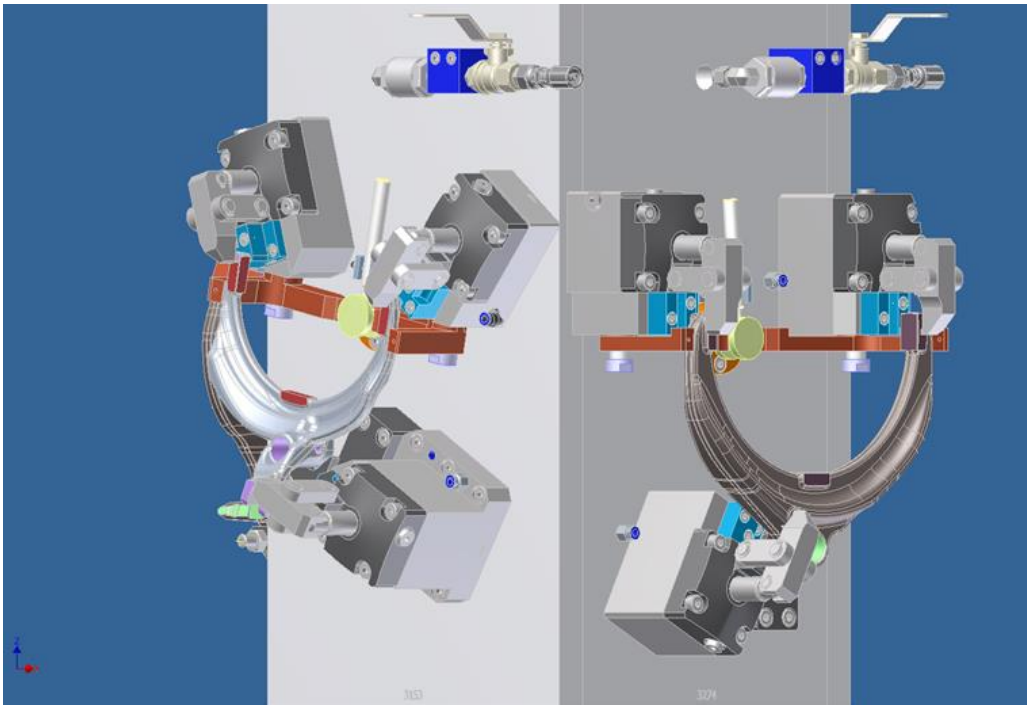

Figure 4.6 *3D CAD of The tool*

The tool (an example is showed on **figure 4.6**) is mounted on CNC center, it is composed principally by a central case on which are assembled support brackets, cylinders and pins according to a configuration that guarantees the stability of the raw parts during the machining process. In particular, the part is kept in position under the action of support brackets activated by the cylinders, which are actuated through an hydraulic circuit located inside the tool; in fact in the figure is possible to notice the presence of taps used for the clamping and unclamping of the raw parts.

4.3 ATB's Route map of WCM

It consists in a map of the plant on which is explained the transformation of this latter on the short, average and long term time horizon; in this way it allows to understand the changes occurred in the plant, clarifying what has done and what it is going to be done in order to obtain that improvement which is the goal of all methodology; therefore, it provides a vision of plant in the future and the direction followed to reach the fixed objectives.

The verification of plant performance level it is documented with a system of external *audit,* they are adopted to evaluate annually the implementation of WCM with respect to the standards World Class, the rational is the following one:

- according to specific check lists, for each of the 10 technical and 10 managerial pillars is evaluated and assigned a step of development of the methodology (from 1 to 7) ;
- then is computed the sum of all steps (marks) obtaining the *Methodology Implementation Index* (**IM**) which maximum is 140 (since 7*20 pillars is equal to 140), see **figure 4.7** ;
- the IM is translated into the IM% which is compared to a global evaluation scale in such a way to obtain the total step of development, see **figure 4.8**;
- moreover on the base of this index, the WCM Association assigns a medal to reward and classify the most prestigious plants in the implementation of the methodology, it represents a benchmark between the enterprises that decide to adopt the WCM model, see **figure 4.9**.

	ROUTE MAP WCM	Q3/2015	2016	2017	2018	2019	2020	2021	2022	2023
Pilastri Tecnici	1. SAFETY	1	2	3	3	4				
	2. COST DEPLOYMENT	0	0	1	1	2				
	3. FOCUSED IMPROVEMENT	1	2	3	3	4				
	4. AUTONOMOUS MAINTENANCE/WORK PLACE ORGANIZATION	0	1	2	3	4				
	5. PROFESSIONAL MAINTENANCE	0	1	1	1	1				
	6. QUALITY CONTROL	1	2	3	3	5				
	7. LOGISTICS/CUSTOMER SERVICE	0	1	2	3	4				
	8. EEM	0	1	2	2	3				
	9. PEOPLE DEVELOPMENT	0	1	2	3	3				
	10. ENVIRONMENT	0	1	2	2	2				
Pilastri Manageriali	1. MANAGEMENT COMMITMENT	1	2	3	3	5				
	2. CLARITY OF OBJECTIVES – KPI	1	2	3	3	5				
	3. ROUTE MAP TO WCM	1	2	3	3	5				
	4. ALLOCATION OF HIGHLY QUALIFIED PEOPLE TO MODEL AREA	1	2	3	4	5				
	5. COMMITMENT OF THE ORGANIZATION	1	2	3	4	5				
	6. COMPETENCE OF ORGANIZATION TOWARD IMPROVEMENT	1	2	3	3	4				
	7. TIME AND BUDGET	1	2	3	3	5				
	8. LEVEL OF DETAIL	1	2	3	4	5				
	9. LEVEL OF EXPANSION	1	2	3	4	5				
	10. MOTIVATION OF OPERATORS	1	2	3	4	5				
Total	IM (punti)	13	32	51	59	81	0	0	0	0
	IM (%)	9%	23%	36%	42%	58%	0%	0%	0%	0%
	Step attuale	1	1	2	2	3				
	Target Step	1	1	2	2	3	3	4	4	5
	media step pilastri tecnici	0	1	2	2	3				
	media step pilastri manageriali	1	2	3	4	5				

***Figure 4.7** ATB Route Map of WCM*

IM %	step
0-35	1
36-55	2
56-65	3
66-75	4
76-80	5
81-90	6
91-100	7

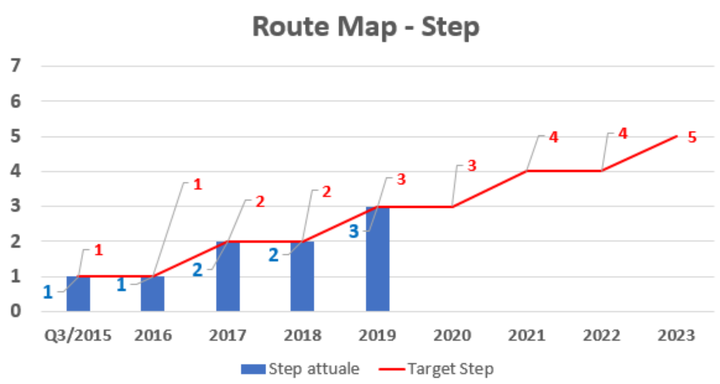

***Figure 4.8** Total step of development*

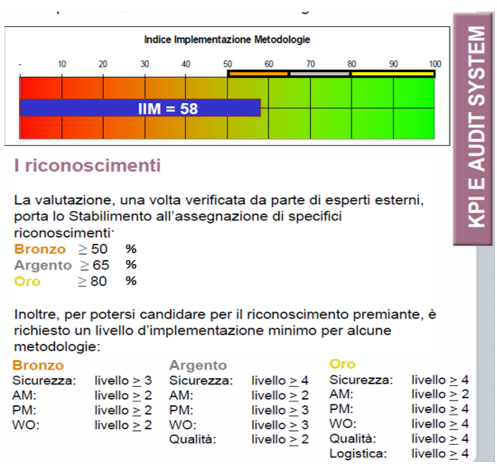

Figure 4.9 *WCM Medal*

For what concerning its Route Map, ATB is at the third total step of development (therefore at the beginning of preventive phase, see **figure 4.10**) ; it is not yet a bronze medal even if IM%=58%, since the Professional Maintenance Pillar (PM) has to be still developed to step 2 (now it has been developed just until the step 1).

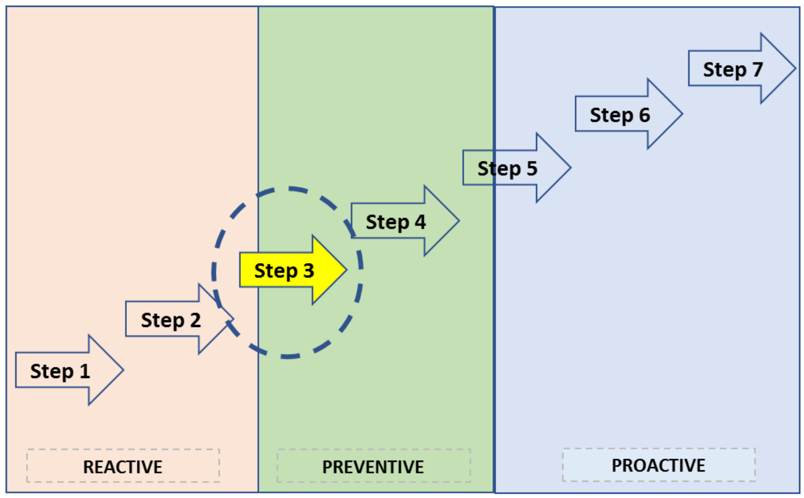

Figure 4.10 *Actual situation*

5 Forno Canavese: the forging plant

5.1 Forging technology

During a forging process, an initial part (a billet for example) is plastically deformed between two tools (two dies for example) in order to obtain the desired final shape, in this way the part having a simple geometry is transformed into a complex one.

Forging processes usually produce a very small quantity of scrap, the final part it is generated in a very short time, usually in one or a few strokes of a press or hammer. For this reason, forging processes offer potential savings in terms of energy and material, especially in large production quantities, where tool costs can be quickly amortized. Moreover, for the same weight, parts produced by forging exhibit better mechanical properties and reliability than those produced by casting or machining.

Forging is a technology developed and improved by experience. During the years, a lot of know-how and experience has been achieved in this field, especially by trial-and-error methods. The forging industry has been capable of providing sophisticated parts, produced following rigid standards, and from new developed, difficult to form alloys.

The metal flow, the heat generation and flux during plastic deformation, the friction at the tool/material interface and the relationships between microstructure and process conditions are difficult to predict and analyze. Often to produce forgings, numerous forming stages, called preforms, are required to transform the initial simple shape into a complex one without causing material failure or depleting material properties. Therefore, the most important objective of every method of analysis is to assist the engineer in the design of both forging and preforming sequences.

The number of forming stages required depends on a lot of factors such as the global shape, shape complexity, and material. Part complexity is increased by different features, including:

- presence of thin sections in the final part;
- important changes in the cross section area of the final part;
- forging shape requiring the die parting line to be inclined (see **Fig. 5.1**)

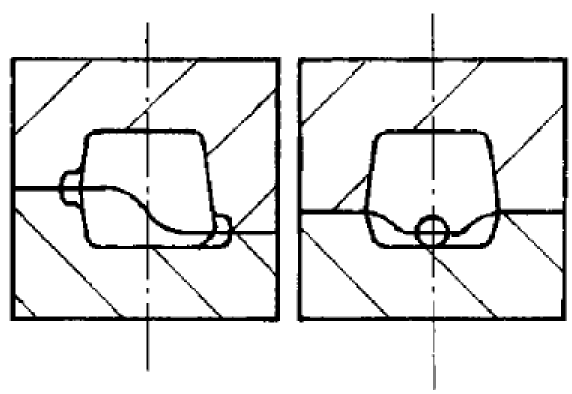

Figure 5.1 *Forging shape requiring an inclined die parting line.*

In the market there are a large number of forging processes available, the main types are referred to as *closed die a*nd *open die forging*. The one exploited in Forno Canavese plant is *Closed (or impression) die forging with flash*.

5.1.1 Closed/impression die forging with flash

During this process, a hot billet is formed in dies (usually having two halves) exploiting the pressure to compress the metal and to fill the die impression. The material in excess is extruded through a narrow gap and appears as flash around the forging at the die parting line (see **figure 5.2**).

- **Equipment:** Anvil and counterblow hammers, mechanical, hydraulic and screw presses.
- **Materials:** Carbon and alloy steels, copper alloys, aluminum alloys, magnesium alloys, beryllium, nickel alloys, stainless steels, titanium and titanium alloys, niobium and niobium alloys, iron and nickel and cobalt superalloys, molybdenum and molybdenum alloys, tungsten alloys, tantalum and tantalum alloys.
- **Process variations:** Closed die forging with longitudinal flash, Closed die forging with lateral flash.
- **Application:** Production of parts for automobiles, tractors, trucks, aircrafts, railroad and mining equipment, energy engineering production and general mechanical industry.

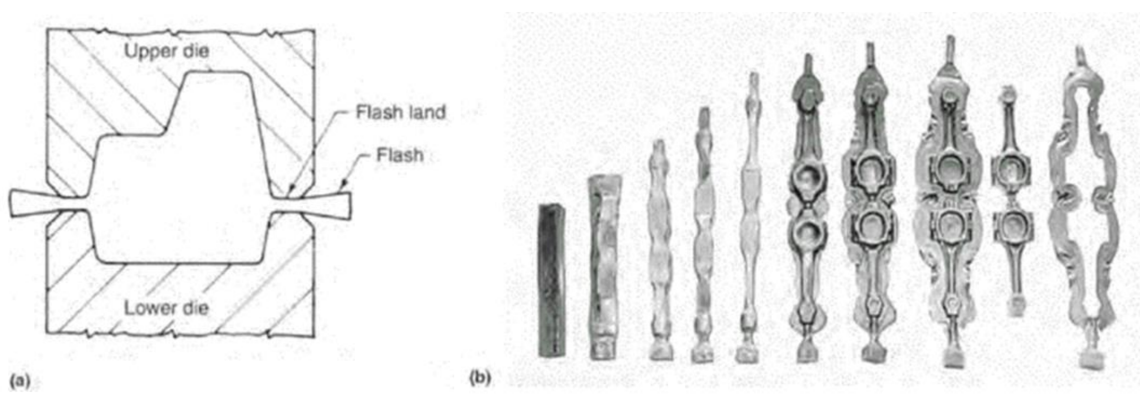

Figure 5.2 *Closed die forging with flash. (a) Schematic picture with flash terminology.(b) Forging sequence in closed die forging of connecting rods*

Differently, *open die forging* is a hot forging process, where the final forging is incrementally shaped by mean of a lot of hammer blows or pressing between flat or simple dies without completely restricting the metal flow (see **figure 5.2**); here below some typical features:

- **Equipment:** hammers or hydraulic presses.

- **Materials:** steel, aluminum alloys, titanium alloys, copper alloys.

- **Process variations:** shaft forging, slab forging, mandrel forging, upsetting between flat or curved dies, ring forging, drawing out.

- **Application:** forging ingots preforms for finished forgings, large and bulky forgings.

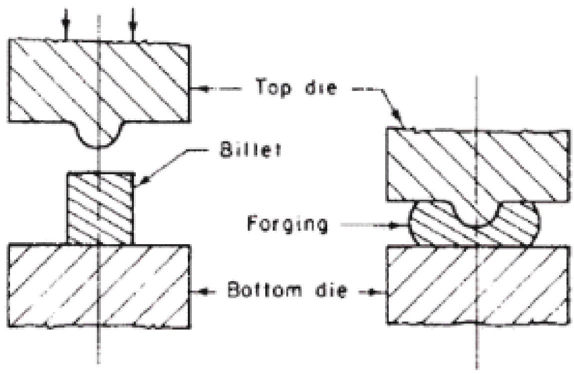

Figure 5.3 *Open die forging*

Table 5.1 *Open and Closed Die Forging Processes in Comparison*

OPEN DIE FORGING	CLOSED DIE FORGING
BENEFITS	
• Better fatique resistance and microstructure • Finer grain size • Higher strength and longer part life • Less waste of material • Remarkable cost savings	• More material available • Cheaper for large volume production • Better surface finish • Less machining required
DRAWBACKS	
• It is not capable to guarantee severe tolerances • Machining is usually required to achieve accuracies and features desired	• Not convenient for small volume production due to high cost of die production • Dangerous working environment • Set up cost is very high due to high cost of machines • Special building provisions must be adopted to face the powerful vibrations

5.1.2 The flash: role and estimation

Flash is the excess of material that squirts out of the narrow gap at the die parting line as a thick ribbon of metal. Therefore, the flash is actually scrap material and could have in many cases a volume that is more than 50% of the final part one, in particular the quantity of flash produced during the process increases with the complexity of the forging. Anyway, the flash production is a necessary step of the process, its formation is required to ensure good die filling, in particular for tall and thin shape features.

Figure 5.4 shows the billet deformation that occurs during the forging process of a relatively simple part: at the beginning of initial material deformation the corresponding forging load is relatively low, the material moves sideways to form a flattened shape. However, to force the material to flow into the extremities of the die cavity, the sideways material must be restricted. Therefore, the flash formation has this role; a narrow flash land around the dies parting line restricts the sideways flow of the material.

During the final steps of the process, the metal is extruded through the flash land to the flash gutter; as the deformation takes place, the gap between the flash lands begins to restrict the lateral flow of material, through an increase of friction and other forces. At this point, the forging load begins to rise bringing to an increase of the pressure inside the die, this increase of pressure causes material to flow into the extremities of the die cavity. At the final step of die closure, the forging load reaches the maximum value and the complete die filling is achieved; at this instant, the final portion of the flash squeezes through the flash land. The choice of appropriate geometrical values for the flash land (gap and width) is a critical issue, it strongly affects the correct die filling during the process and the occurrence of excessive forging loads

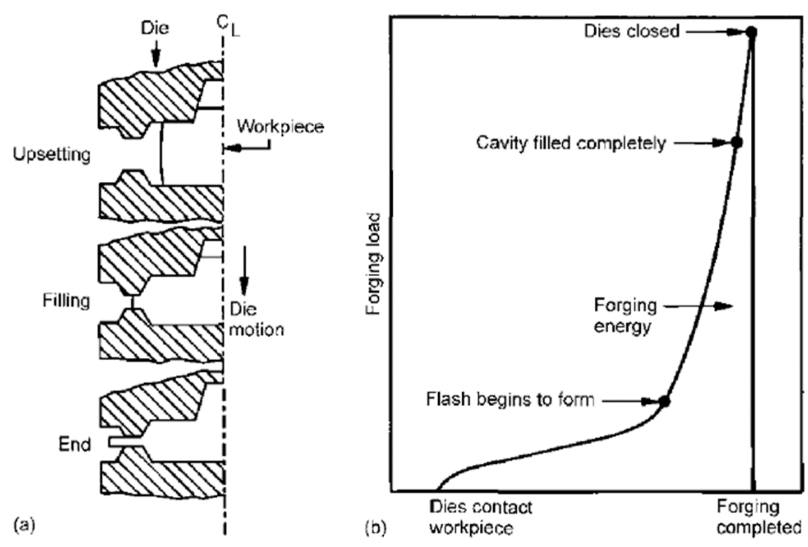

***Figure 5.4** "(a) Forging of simple part shape. (b) Forging load as function of the press stroke"*

Figure 5.5 shows the typical configuration of the flash land and the flash gutter for a forging, the gutter has to be large enough to accommodate the flash that is produced during the process. The choice of the proper thickness and width of the flash land is an important step of the forging design process, as matter of fact, if the geometry is not correct the dies could not fill completely and the forging loads could reach excessive values.

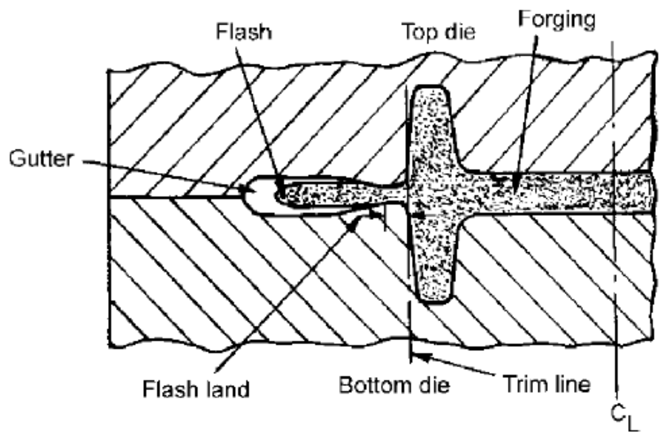

Figure 5.5 *Flash land and flash gutter configuration*

Usually the choice of the flash land dimensions was based on experience with forgings of a similar type, as result have been developed a number of empirical formulas for the calculation of flash land geometry, some formulas does not take into account of the forging complexity, other ones are based on statistical analysis.

The costs for the material are determined considering the weight of the finished forging and the weight of material wasted during the process; the material losses are mainly the result of the flash produced during forging, but further losses may occur due to the formation of scale caused by material oxidation that takes place during heating, and material contraction (shrinkage) that occurs during the cooling after forging process.

The quantity of flash produced during the forging process is strongly affected by the shape of the part, there are basically two systematic approaches for the estimation of flash amount:

1- Adoption of statistically obtained average ratios of the gross to net weight of parts for different classes of forgings and weights.

2- Utilization of average values of the flash weight per unit length of the flash line for different classes of forgings and weights.

5.1.3 Forging allowances

Considering the parts produced by hot forging, these require machining on mating surfaces in contact with other parts in the final product. Therefore, the shape features of a forging are obtained starting from the machined part, by adding different allowances to the machined surfaces; some of these allowances involve also surfaces that will not be machined. **Figure 5.6** shows for example the cross section of forging that will be machined all around, the machining allowance is the first one added to the machined surface; this quantity is added to any dimensional tolerance and is sufficient to get a clean surface after machining.

Draft is an angle allowance applied to surfaces parallel to the direction of die closure, it is added to facilitate after forging the release of the part from the die. Generally, draft allowances added to inside surfaces are greater than those ones added to outside surfaces, this is due to the tendency of the part during cooling to shrink more onto protuberances in the die.

Eventually, additional radii must be applied to all edges and corners in the part, these radii are required to promote the flow of material and to ensure good die filling; hence, larger radii are adopted for difficult to forge materials. Moreover, sharp corners act as concentrator of stresses, therefore they can be responsible of premature die failure.

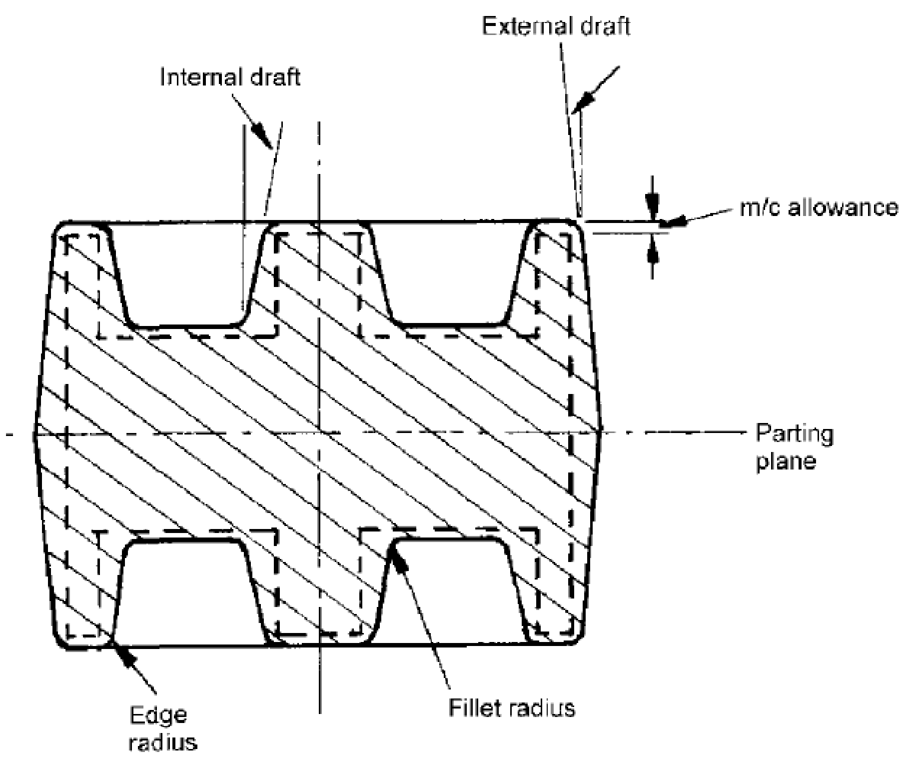

Figure 5.6 *Forging allowances*

5.1.4 Webs and ribs

As putted into evidence in **figure 5.7,** a web is a thin part of the forging parallel to the parting line (plane that divides the upper die from the lower one), while a rib is always a thin portion of the forging but perpendicular to the same line; these part features make the metal flow difficult as they become thinner.

Webs are often added to the parts for a question of strength or other reasons, and are often followed by peripheral ribs. These webs brings to an increase of the forging load because of the large contact area, which increases therefore cooling rate and friction. In particular, if the finished part is characterized by some holes, then these are filled with webs at the die parting line, later these ones are removed by piercing during trimming (flash removal process) as explained soon. Obviously, the material inside webs is additional waste material and is responsible of an additional cost per part.

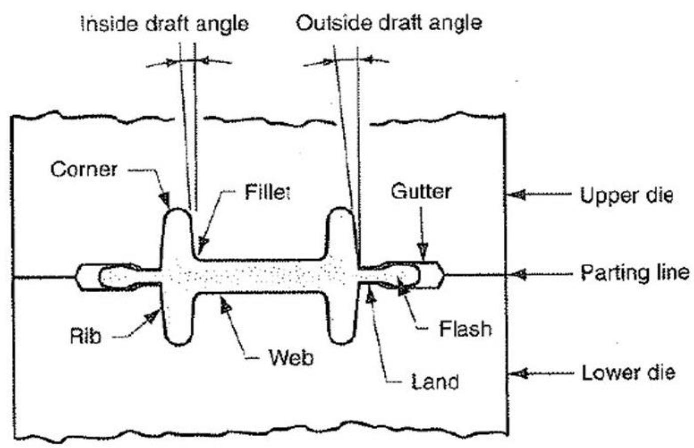

Figure 5.*7 Webs and ribs*

5.1.5 Preforming operations

Usually to produce a forging are required numerous preforming stages (called preforms), in such a way to pass from the simple geometry of the billet (usually in forging the starting raw material has a simple shape, it is round or square section billet) into a complex one without causing any material failure or depletion of the material properties. Actually, very few forgings are produced resorting to a single forming stage, since it usually results in a large quantity of flash to ensure die filling and/or large forging loads (die loads).

Most of times, a set of preforming operations is required to bring the initial billet shape closer to the final one before the last forming stage in the finishing die impression (the *finisher*). The number and kind of these operations is strictly related to the finished forging geometry; **figure 5.8** shows for example, for a simple connecting-rod forging, the typical forging sequence.

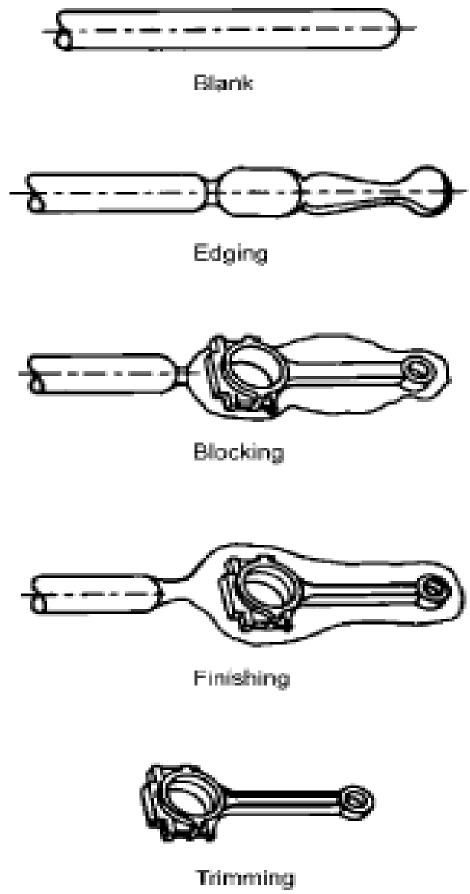

Figure 5.8 *Forging sequence for a connecting rod.*

The design of preforms is a sort of "art" heavily based on the skills of experienced operators. From this point of view, there are also alternative approaches for the design of preforms based on the application of finite element analysis, but they are still object of research.

The first forging stage consists usually in a simple die impression having sometimes just flat faces, called *buster*, the aim of this die is to induce the initial flattening of the billet, in this way it is also removed the scale produced by oxidation during heating. In case of simple geometries, the material is then forged in the *finishing die impression*. However, for most of parts one or two additional preforming stages are required.

The die cavity before finisher is called *blocker* (or *semifinisher*), it is a smoothed out version of the *finisher* with larger radii and thicker sections. The *blocker* preforming stage is usually included to increase the life of the *finisher;* its sections are designed starting from the *finisher* ones using empirical design rules. **Figure 5.9** shows a typical *blocker* cross section compared to *finisher* one. If the final forging it characterized by tall and/or thin geometrical features (such as ribs and webs), then an additional *preblocker* having thicker sections and larger radii than the blocker could be also required.

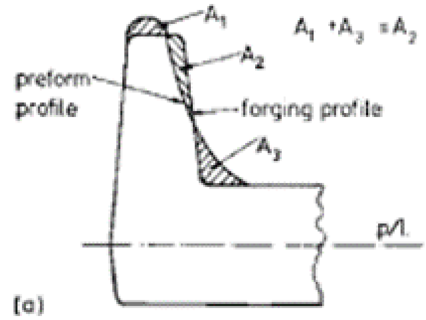

Figure 5.9 *blocker cross section compared to finisher one*

In case of long parts (as a connecting rod) the first preforming stages are simple forging operations, these stages are aimed to distribute the material along the length of the forging, in order to get a mass distribution closer to that one of finished part. This is achieved by resorting to simple dies called *fullers*, followed by the die called *edger* (or in the United Kingdom a *roller die*). For example, considering the connecting-rod case, after two fullering operations followed by one edger die, the result is a dumbbell shape having an axial mass distribution similar to the final forging. Following these preforming stages, the part is then formed according to the finished shape; for simple geometries this is done directly in the finishing die impression, but usually as seen before a *blocker* die is used, and in some cases, a *preblocker* is required too. Moreover, if the final forging is characterized by bends along longitudinal axis, a *bending stage* is added to preforming operations. In this case, *fullers* and *edgers* are followed by the *bending die impression*.

As seen before, many die impressions are required to process a hot forging. For small and medium-sized forgings these impressions live on a single die block. **Figure 5.10** shows two examples of die layout. Many factors must be considered in the layout of die impressions, as for example the minimum spacing between die impressions. Generally, the *finisher* and *blocker* are designed to be in the center of the die block, with the *edger* and/or *bending die* to one side, and the *fullers* in the other one.

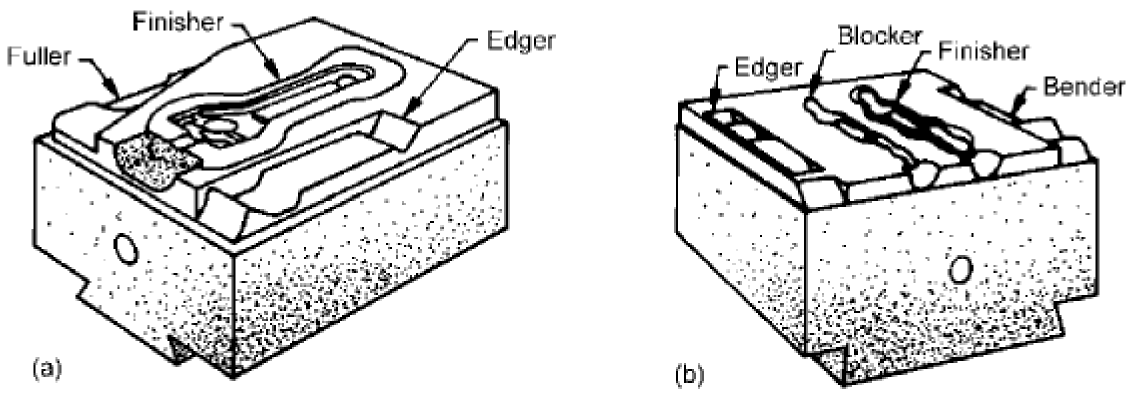

Figure 5.10 *Two examples of die layout*

5.1.6 Removal of the flash

In hot forging, the final stage consists is the removal of the flash to get the final forging. The flash removed is material in excess, and for some forgings can represent more than the 50% of the total raw material used. It is usually removed by mean of a *trimming die* (*trimming process*), which cut the flash off in correspondence of the forging parting line. The webs through holes are also pierced out at the same time (*piercing process*) or during a subsequent step. Trimming operation is usually carried out on a mechanical press adjacent to the main one used for forging, with the forging still hot, and usually is the last operation performed on the part once forged (additional machining could be required too). The **figure 5.11** schematically represents the trimming operation. The flash can be removed also by a machining operation, as for example *band sawing*, but it is slow and more expensive.

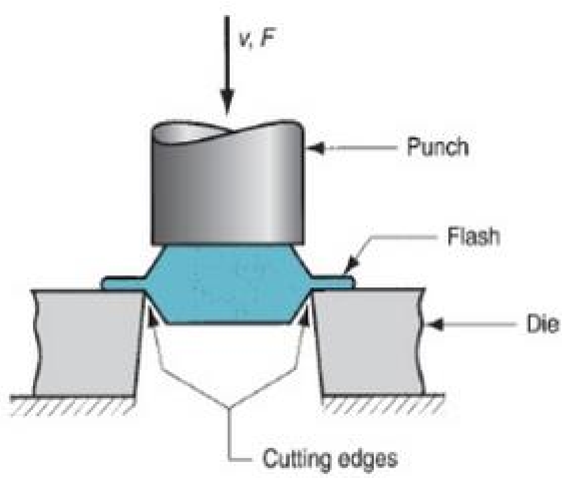

Figure 5.11 *The trimming operation*

A *trimming machine* (or *flash trimming tool*) basically consists of a punch holder, a punch (male component of the assembly), a die holder (called *shoe* and fastened to the table of the trimming press), a die (female component of the assembly), and a system (mechanical or hydraulic press) to provide the force required by the punch for trimming.

The trimming and piercing dies are characterized by a cutting edge corresponding to the parting line of the forging, therefore, the complexity of cut is increased by the presence of an inclined parting line. During trimming the forging is positioned on the die cavity, and the punch, moved by the press ram, pushes it through the trimming die removing the flash that is used to support the forging, hence, the flash stay on the cutting edges while the forging falls down inside the die cavity. Because of this fact, the design of the punch is fundamental to avoid the distortion or damage of the part.

Similarly, the *piercing tool* for cutting the webs through the holes consists in a piercing punch and a piercing die, where the die is characterized by cutting edges. Piercing operation can be carried out on a devoted press or on the same press when *combined trimming and piercing tools* are available; in this case both the cutting operations are performed in two different strokes or simultaneously.

Figure 5.12 here below schematically represents the trimming operation, performed by a trimming tool, as used in the ATB forging plant.

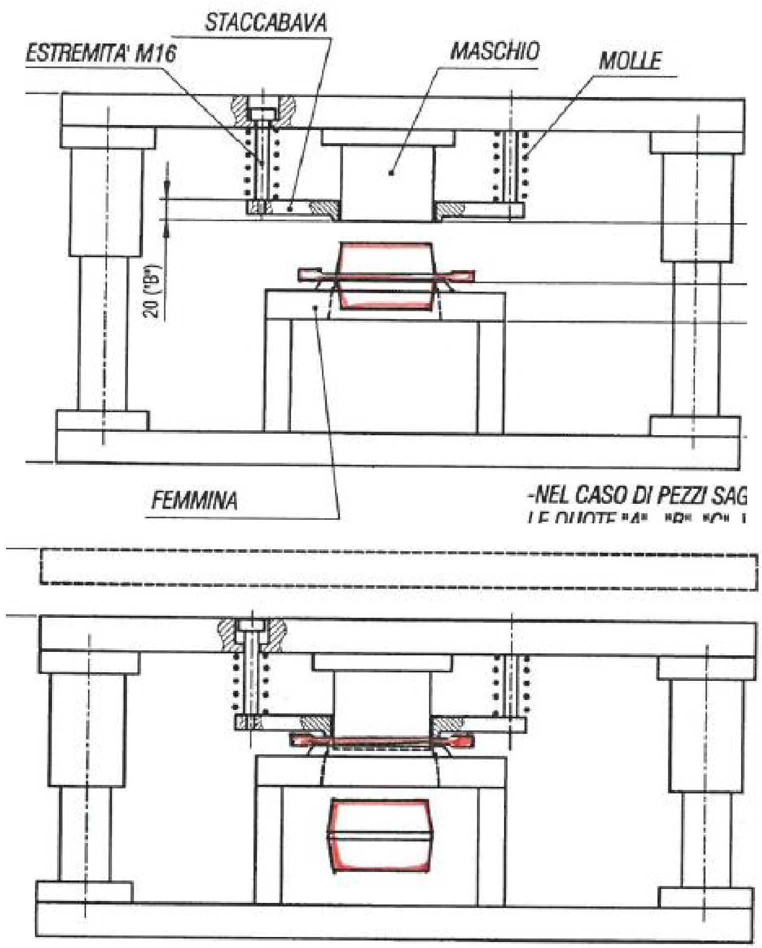

Figure 5.12

Figure 5.13 here below schematically represents the trimming and piercing operations, performed in two different strokes by combined trimming and piercing tools, as used in the ATB forging plant.

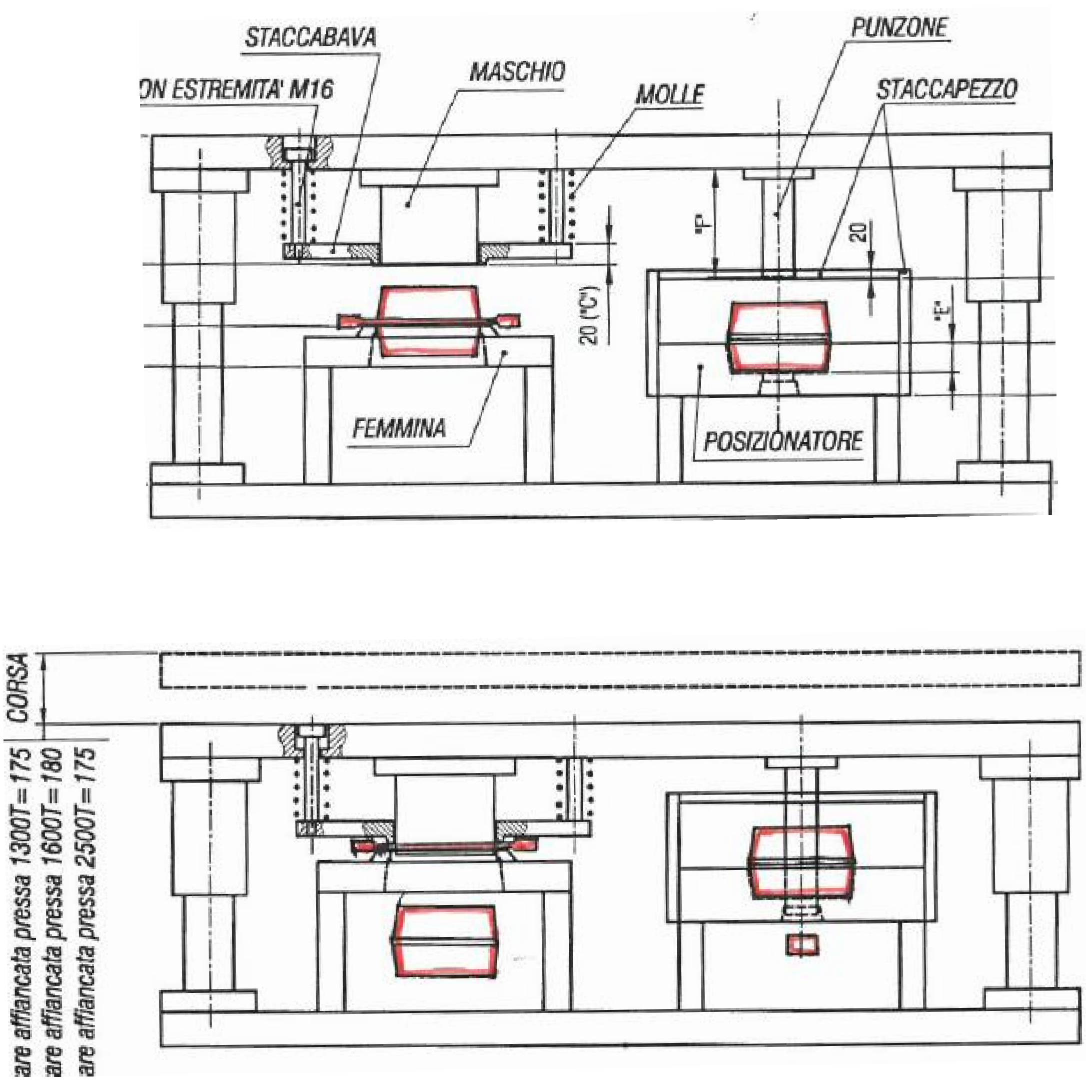

Figure 5.13

Figure 5.14 here below schematically represents the trimming and piercing operations, performed simultaneously in one stroke by combined trimming and piercing tools, as used in the ATB forging plant.

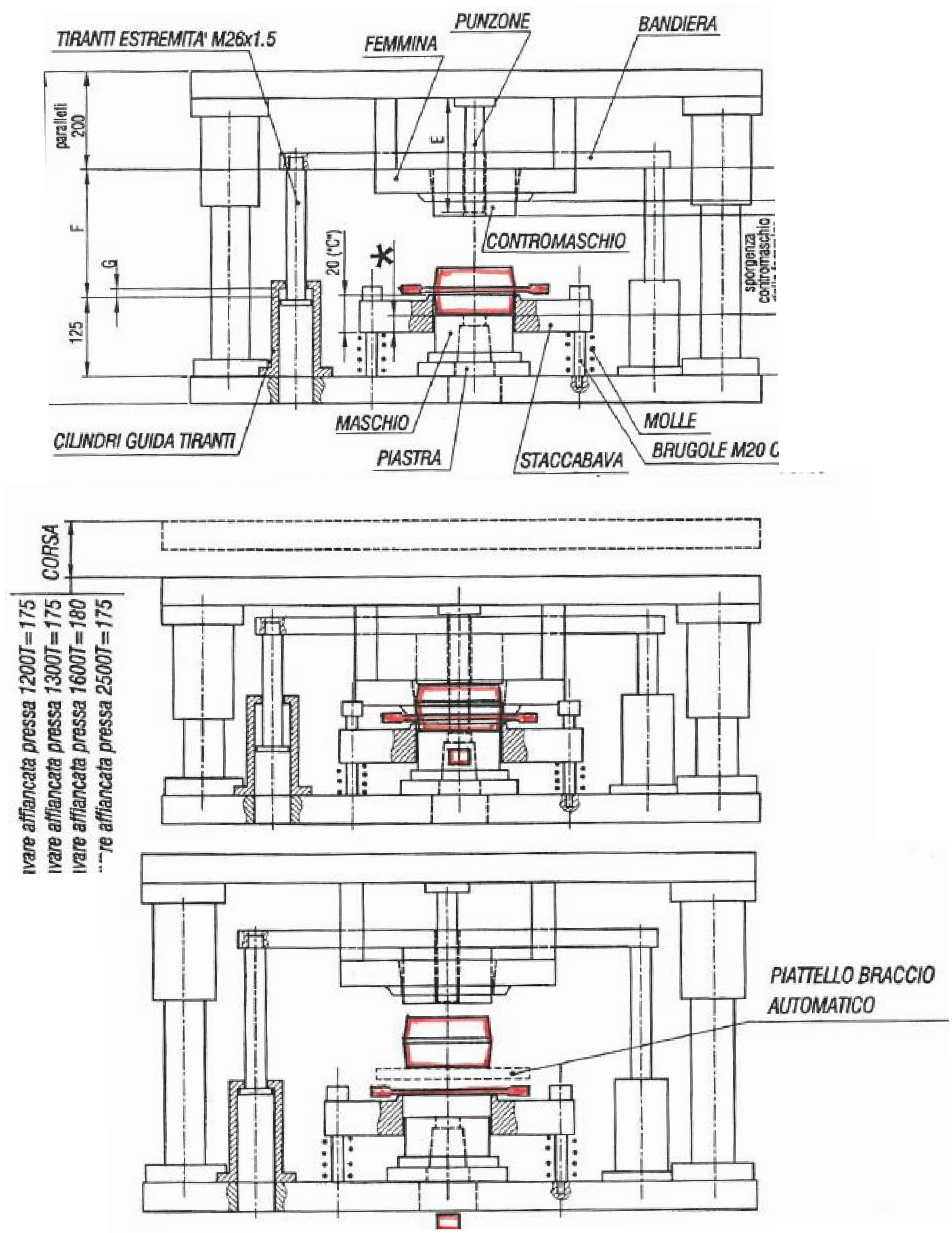

Figure 5.14

5.1.7 Forging defects

When a forging plant begins to experience defects in its process, it should try to find the cause of the problem, perform a corrective action and prevent its recurrence. From an economical point of view, as well as, from a quality perspective, it is better to control the process in such a way to avoid defects rather than rejecting the defective parts during final inspection. A brief description of typical defects, causes and possible remedies are listed here below:

1. **Unfilled sections**: sections of the die cavity not completely filled by metal flow**.**
   Cause: wrong design of forging die.
   Remedy: Proper forging die design, raw material and heating

2. **Cold shut**: it appears as a small crack at the corners of the forging.
   Cause: Small fillet and corner radii responsible of improper metal flow that ends as a cold shut, in particular, two surfaces of metal fold touch each other without welding completely.
   Remedy: Increase of fillet and corner radii of the forging die.

3. **Scale pits**: they are seen irregular depressions on the forging surface
   Cause: insufficient cleaning of the material used for forging, oxide present on surface gets merged into the finished forging surface.
   Remedy: Proper cleaning of the material before forging process.

4. **Die Shift** : Misalignment of the forging in correspondence of the flash line.
   Cause: the misalignment of the two die halves
   Remedy: Proper alignment of die halves.

5. **Flakes**: basically internal fractures.
   Cause: a rapid cooling that causes the exterior to cool quicker than interior material
   Remedy: adoption of a proper cooling strategy.

6. **Improper grain flow**
   Cause: improper design of the die that makes the metal flow not following the desired directions.
   Remedy: Proper die design.

7. **Cracking at the flash:** it consists in a crack that penetrates into the interior material after trimming of the flash.
   Cause: very thin flash.
   Remedy: Increasing flash thickness positioning the flash to a less dangerous region of the forging.

8. **Residual stresses**
   Cause: improper cooling of the forging.
   Remedy: Slow cooling of the forging for a certain period of time.

9. **Surface cracking**
   Cause: too low temperature.
   Remedy: increase of the work temperature

5.1.8 Lubricant

In hot forging, the metal flow is due to the pressure transmitted from the dies to the starting hot billet. Therefore, the friction at the die/part interface greatly influence flow of metal, the formation of internal and surface defects, stresses on dies, and load requirements.

Figure 5.15 illustrates as this phenomenon applies to the upsetting of a cylindrical part. As Figure (a) on the left shows, ideally without friction, the part deforms uniformly and the resulting normal stress, σ_n , is constant along the diameter. Instead, Figure (b) on the right shows that under real conditions, where frictional stress, τ , is present, the part does not deform uniformly (barreling). Therefore, in this case the normal stress, σ_n , increases from the outer diameter to the center and the forging force is greater than without friction.

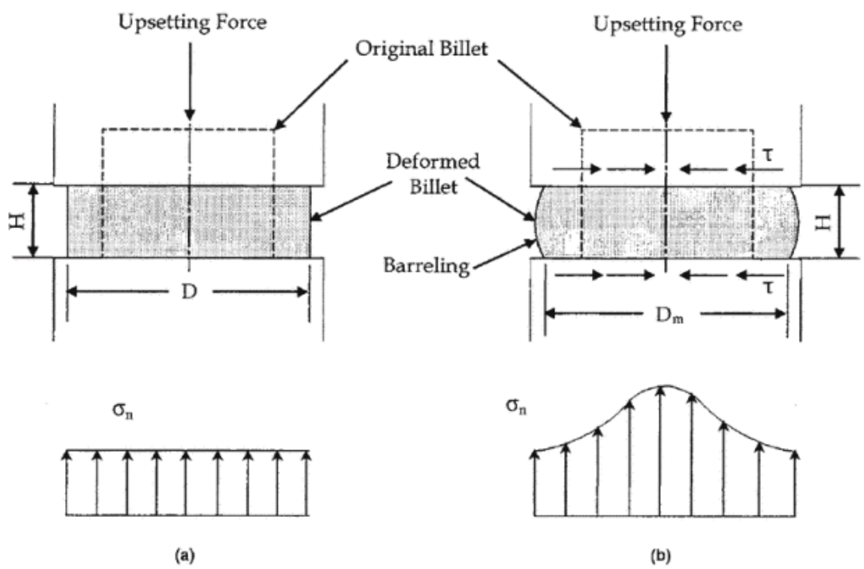

Figure 5.15 *"Upsetting of a cylindrical part. (a) without friction. (b) with friction"*

Friction is controlled by use of proper lubricants depending on different applications; in particular, the lubricant is expected to satisfy most of the following requirements:

- Reduce friction between the dies and the part.
- Act as a parting agent, preventing sticking and galling of the part to the dies.
- Be a good thermal insulator, in order to reduce loss of heat from the part the dies.
- Be a good inert material to avoid reactions that could degrade the dies and the part materials at the temperatures used.
- Be nonabrasive in order to reduce die wear.
- Not produce dangerous gases.
- Be easily removable and applicable to dies and forging.
- Be available at reasonable cost.

Very high die temperatures due to the transfer of heat from the billet to the dies, together with high die stresses are responsible of plastic deformation and wear in the dies. Therefore, in order to increase part quality and tool life, a good lubrication system should allow of minimizing both the shear stresses at the part/die interface and the heat transfer to the dies.

The high temperatures exploited in hot forging make very difficult the use of soaps or organic based lubricants (mineral oils); this because soaps melt and organic based lubricants burn at these temperatures. Therefore, the choices of lubricants are very limited, the four most common lubricants exploited are synthetics, graphite, MoS2 and glass.

In particular, graphite and MoS2 are solid lubricants, because of their molecular structure they induces low frictional stresses. These lubricants are usually mixed with water to get an aqueous solution and sprayed on the dies before loading of the billet. This has two purposes:

- The solution evaporates in contact with the dies, cooling and protecting them against wear due to thermal softening.

- An graphite or MoS2 layer forms on the dies after the evaporation of the aqueous solution, this layer acts as a lubricant and also as thermal insulator against excessive die heating.

Today, because of the low environmental friendliness of graphite and its unpleasant accumulation within the dies, have been developed water based synthetic lubricants. The common lubricants used for hot forging of steels are summarized in **Table 5.2.**

Material	Process	Deformation	Lubricant
Carbon steel	Warm forging	Severe	MoS_2 in aqueous solution Graphite in aqueous solution
	Hot forging	Severe	Graphite in aqueous solution
Stainless steel	Hot forging	Severe	Glass in aqueous slurry or powder

Source: [Schey, 1983]

Table 5.2

In hot forging the application of the lubricant depends on the total forging cycle time, which commonly lasts few seconds; **Figure 5.16** reports the steps of a typical die lubrication process. Therefore, it is essential to apply the proper lubricant as fast as possible. This means that factors as spray pressure, spray angle, lubricant flow rate, spray pattern and spray distance, are very important for the success of hot forging operation.

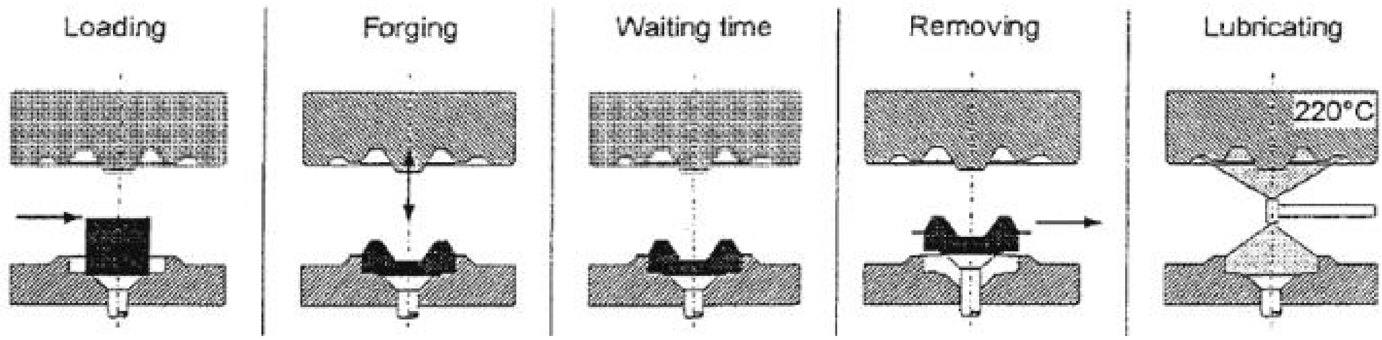

Figure 5.16 *Steps of die lubrication process in hot forging*

5.2 Steps of production and technologies adopted

5.2.1 Steps of die generation

This paragraph is devoted to the collection and explanation of all the operations that are carried out in sequence, and that bring progressively to the die generation as done in ATB. They are performed as follow below:

1. *Client's order*: it consists in a first proposal of the finished product under form of technical drawing sent by the client, with all tolerances, recommendations about surface treatments, and other specific requirements.

2. *Evaluation of the first proposal*: the initial technical drawing is evaluated and modified by the technical team to make it compatible with the industrial production capabilities. For example the initial CAD is modified with the application of draft angles allowances to surfaces parallel to the direction of die closure, they are added to facilitate after forging the release of the part from the die, and their value usually ranges in between the 3 or 5 degrees.

3. *Client’s approval*: Once that the modified drawing is approved by the client, it is possible to proceed with the design of the die.

4. *Die design*: the die is designed by mean of a 3D modeling software, in particular, the shape features of the forging are obtained starting from the machined part, by adding different allowances to the machined surface; some of these allowances involve also surfaces that will not be machined. The final shape of the forging is then obtained by taking into account the material shrinkage (estimated around the 1.2%), therefore, at this point is now possible to choose where to place the die parting line, hence the CAD of the die is obtained.

5. *Preventive forging process simulation and eventual corrections*: execution of finite-element forging process simulation by mean of specific software. The forging process simulation allows to understand with a good level of reliability if the material provided is enough to completely fill the die up, and detect eventual defects like for example surface cracks or metal folds that can act as intensifier of stress. Therefore, in this case, the CAD is preventively modified in such a way to avoid the occurrence of these problems, that are absolutely unacceptable, especially talking about parts intended for safety systems (like brakes for example).

6. *Tool path generation*: the CAD file is translated into a CAM one, from this latter is possible to obtain automatically by mean of the devoted CNC machine software, the tool path required to get the die cavities by milling of the starting block of steel.

7. *Zero setting and die production by milling*: setting on the CNC machine of the origin of the part reference system by 3D taster, and starting of the milling operation (see **figure 5.17**).

Figure 5.17

8. *Tuning of the die:* it consists in the casting of special Pb alloy (having higher density and lower melting temperature than steel) inside the die, the sample part obtained it is subsequently scanned by mean of a manual optical scanner (GOM). Then, the 3D model achieved is superposed by software to the original 3D CAD (the Zero), in such a way to put into evidence the areas in defect or excess of material. Therefore, the die is modified in order to get the optimal forging condition (see **figure 5.18** and **5.19**).

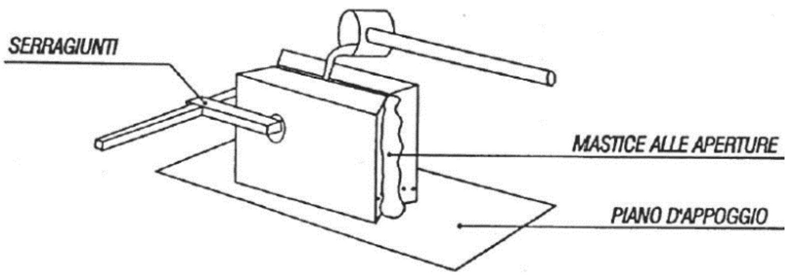

Figure 5.18

Figure 5.19

9. *Thermal treatment (quenching and tempering, nitriding) of the die*: the die is subjected to thermal treatments in order to increase the mechanical properties of the material, in particular, the surface hardness.

   With term "quenching and tempering", we mean the union of two thermal treatments carried out in sequence on particular kind of steels: a temper followed by recovery.

   Temper: this thermal treatment is performed heating the steel up a temperature higher than TA3 (temperature above which is possible to get Austenite in the steel); this temperature is maintained for a certain period of time, in order to obtain from surface to the core the same microstructure. Eventually the steel is cooled very quickly (quenched) in order to achieve the formation of Martensite; this structure is characterized by high hardness and strength, but has a reduced resilience. For this reason temper is followed by a recovery.

Recovery: during this thermal treatment, the steel is heated up until a temperature higher than 550 °C, at these temperatures Martensite transforms into Sorbite, a structure characterized by a good strength and higher resilience at the same time (See **figure 5.20** and **5.21**).

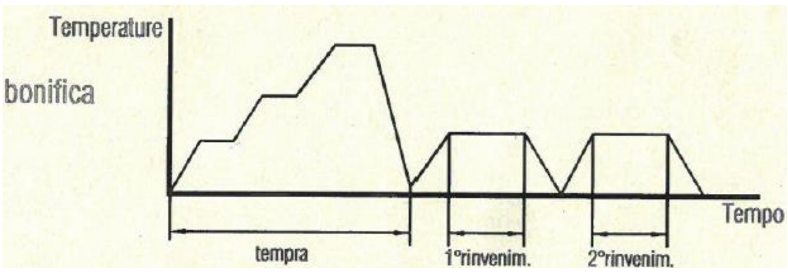

Figure 5.20 *Figure 5.21*

Nitriding: it is a thermochemical process that involves the diffusion of nitrogen into the steel surface causing the increase of surface hardness. In particular, in the case of *ammonia nitriding*, steel is heated up until around 520-540 °C, at this temperatures the ammonia into contact with the heated part dissociates into nitrogen and hydrogen. Therefore, subsequently the nitrogen diffuses onto surface of material (see **figure 5.22**).

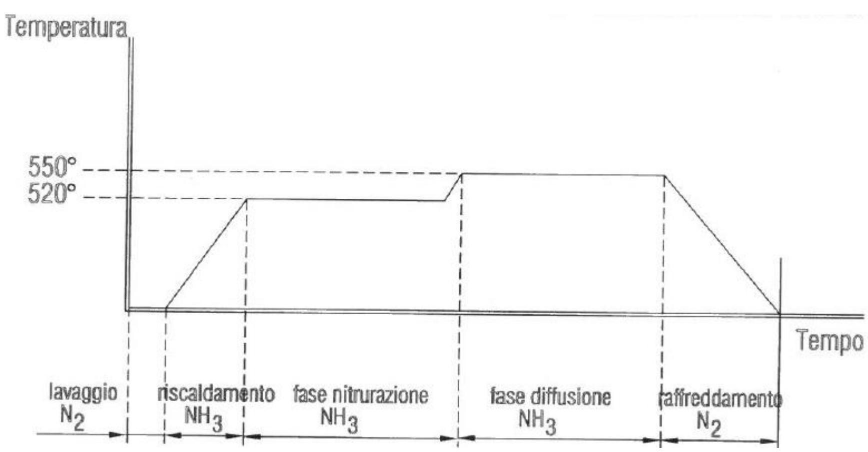

Figure 5.22

10. *Grinding:* After heat treatment, the die's surface is grinded in such a way to face the eventual deformations due to the thermal processes (see **figure 5.23**).

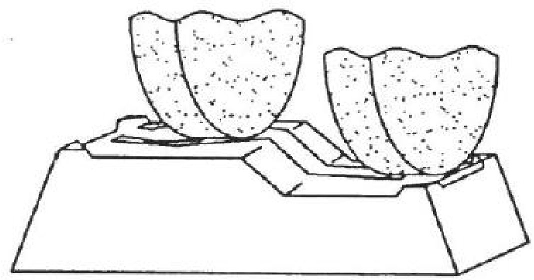

Figure 5.23

11. *Test of hardness:* eventually, the surface hardness of the die is e tested in laboratory to verify the satisfaction of standard requirements *(50 Rockwell)*

Figure 5.17 *Taster for Zero setting of the part.*

Figure 5.18 Casting of special Pb alloy inside the die.

Figure 5.19 *Scanning of the sample part by mean of the optical scanner (GOM).*

Figure 5.20 *ATB Quenching and tempering cycle as represented on Temperature-Time diagram.*

Figure 5.21 *ATB Furnace* for thermal treatments.

Figure 5.22 ATB Nitriding cycle as represented *on Temperature-Time diagram.*

Figure 5.23 Grinding of the die by CNC Grinding machine.

5.2.2 Steps of raw part generation

This paragraph, in a way analogous to the previous one, is devoted to the collection and explanation of all the operations that are carried out in sequence, and that bring progressively to the raw part generation as done in ATB. They are performed as follow below:

1. *Cut of the bar:* at the beginning, the initial bar of length L is cut in N billets of length l, by mean of a cutting machine.

   During this phase, part of total starting material can be lost in different ways (see **figure 5.24**):

- Because of the thickness of the cutting blade (in red in the picture).
- Because of the portion of the bar required for clamping (in blue in the picture).
- Because of the scrap material due to the subdivision of the bar into billets of equal size (in yellow in the picture)

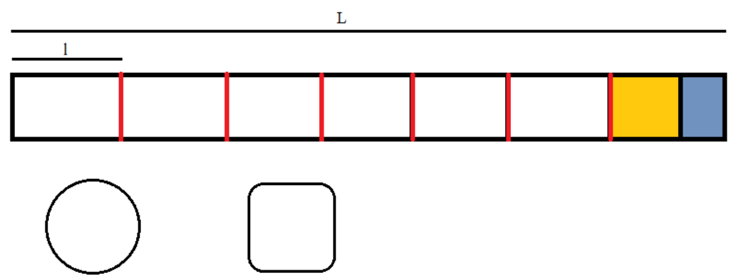

Figure 5.24

2. *Insertion of billets on the loader*: the billets, once that are inserted in the loader are transported by a conveyor chain to the induction furnace.

3. *Heating of the billets:* the induction furnace heats the billets up until 1200 °C, outside the furnace, the billets having higher temperature are scrapped since their internal microstructure is compromised; instead, billets with lower temperature are recovered since reusable. All the billets having the desired temperature are transported by a conveyor chain to the forging press (see **figure 5.25**, **5.26** and **5.27**).

4. *Forging*: the raw part is forged by mean of two or more forming stages depending on its geometry.

5. *Trimming and piercing operation:* the flash is removed from the forgings by mean of a trimming die, and the webs through holes are also pierced out at the same time or during a subsequent step.

6. *Cooling*: the forgings collected into metal boxes are positioned outside the plant for cooling.

7. *Coining:* eventually, the raw parts are coined before to be machined, in order to correct eventual deformations and misalignments

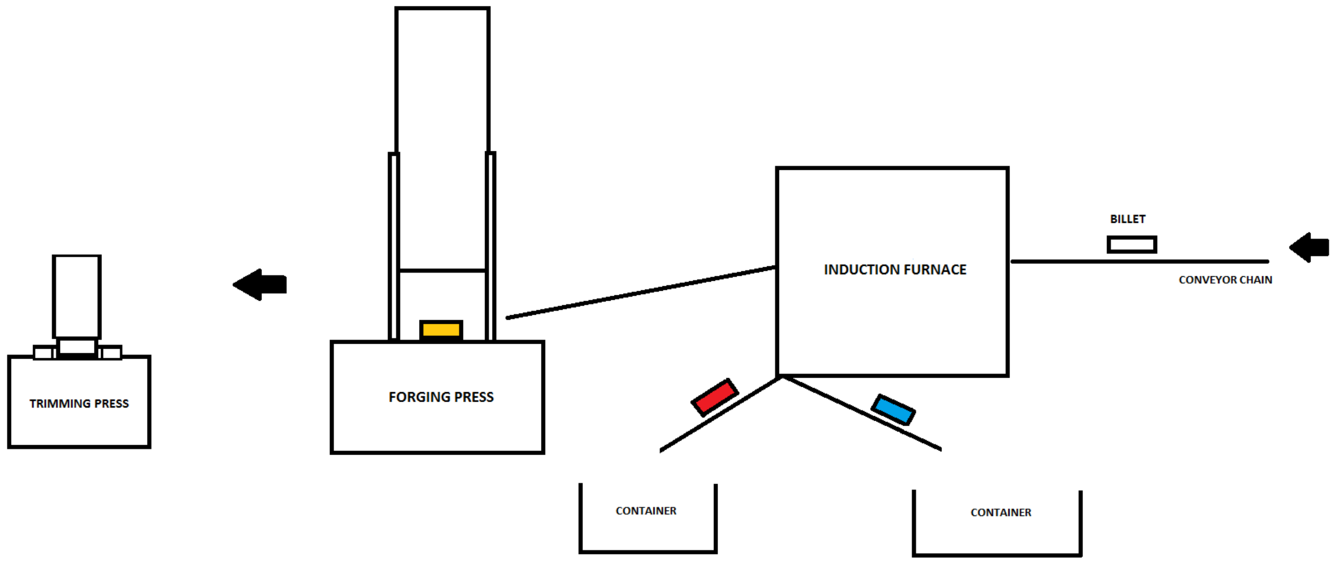

Figure 5.25

Figure 5.26

Figure 5.27

Figure 5.24 *Schematic representation of the bar, type of sections disposable and losses due to the cut.*

Figure 5.25 *Schematic representation of the forging process.*

Figure 5.26 *Incandescent billets, scrapped because of temperature higher than desired one.*

Figure 5.27 *Scrapped billets because of temperature lower than desired one.*

5.2.3 Induction furnace

This paragraph is aimed to describe the technology exploited by ATB for the heating of the billets prior to forging in the press, in particular, are going to be discussed the physical concepts behind induction heating, its benefits with respect other technologies commonly adopted and some critical issues.

5.2.3.1 Operating principle of induction heating

"Induction heating is a process that consists in heating an electrically conducting thing by electromagnetic induction, during the process eddy currents are generated in the metal and the resistance of the object leads heating of this latter because of Joule effect. Therefore, this process makes possible to heat a metal part without open flames (or other heat sources) and without direct contact."

The induction heater it is characterized by an electromagnet (coil), through which alternating current (AC) at high frequency is passed. The frequency adopted depends on several factors, as the size of the object and type of material.

The alternating current flowing through the coil generates a magnetic field concentrated in the enclosed area (see **figure 5.28**), in particular, the intensity of the field varies in relation to the intensity of the current passing through the coil. Eddy currents are induced in the electrically conductive object (a billet, for example) positioned inside the coil, and its resistance leads to an increase of temperature in the area where the eddy currents are flowing because of Joule effect (see **figure 5.29**).

An increase of the intensity of the magnetic field brings to an increase of the heating effect, moreover, it is also affected by the magnetic properties of the material and the distance between the object and the coil.

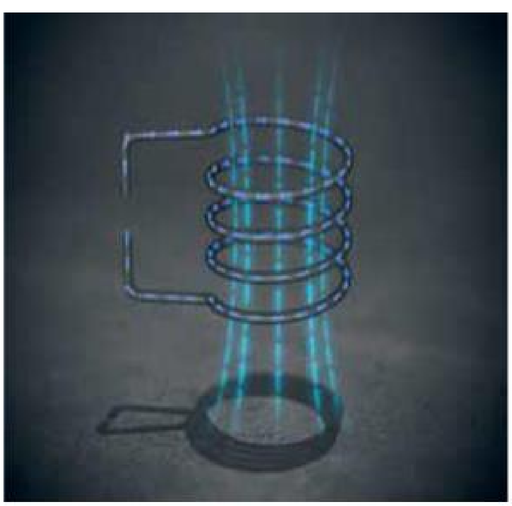

Figure 5.28

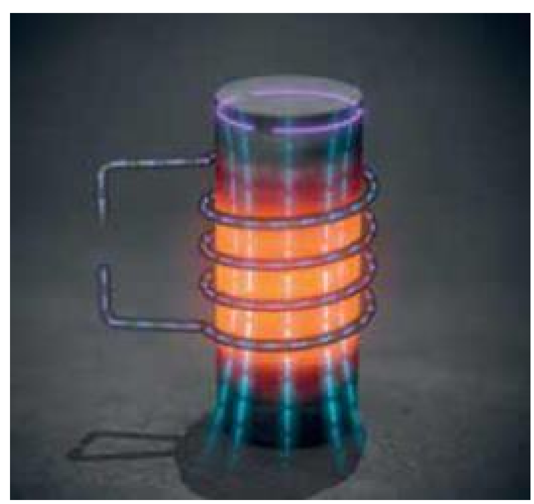

Figure 5.29

More precisely, eddy currents are currents induced in conductive metal masses that are immersed in a variable magnetic field or that, moving, cross a constant or variable magnetic field. In any case, it is the variation of the magnetic flux that generates the circulation of electrons (i.e. current) in the conductor, in accordance with Faraday's law. These electrons moving in vortices generate in turn a magnetic field in the opposite direction to the variation of the applied magnetic field, in accordance with the Lenz's law (see **figure 5.30**). In this case, greater is the intensity of the swirling currents that develop and stronger is the magnetic field that they generate.

The current that develops in the conductor has a swirling shape because the electrons are subject to the Lorentz force, which is perpendicular to the direction of the moving electrons. Moreover, they rotate to their right, or left, depending on the direction and variation (increase or decrease) of the applied magnetic field.

As we have already said eddy currents causes energy losses heating the conductor, the phenomenon is called Joule effect: in a conductor subjected by a current, part of the electrical power is dissipated under form of heat. This dissipated power is the result of the collisions of the electrons with the atoms of material, by collision the kinetic energy of electrons is transferred to the atoms of material, therefore, these start to vibrate around their condition of equilibrium causing an increase of temperature.

This phenomenon is negative in many applications since this heat generation has no useful effect. For example in transformers and electric motors it causes a decrease in efficiency; but, losses due eddy currents are not always an undesired phenomenon. There are some applications based on it like for example induction furnaces.

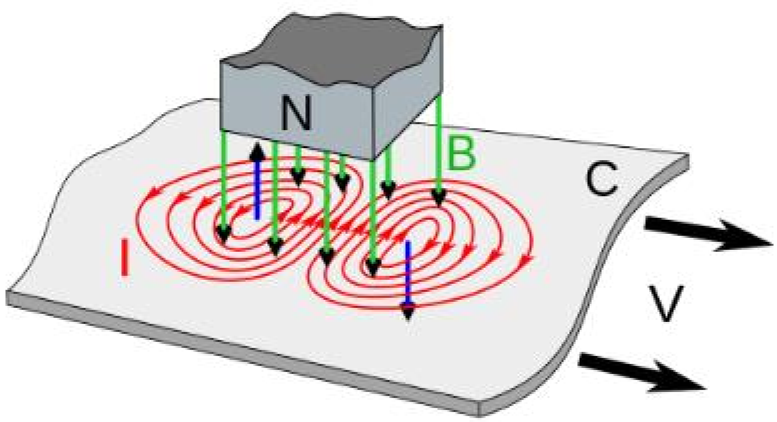

Figure 5.30

Figure 5.28 *Magnetic field due to flowing of current in the coil.*

Figure 5.29 *Heating of the billet due to Joule effect induced by eddy currents.*

Figure 5.30 *Eddy currents (in red) induced by a variable magnetic field (in green).*

5.2.3.2 Use of induction heating in forging

In hot forging the raw material is heated above the temperature of recrystallization before forging, usually 1100°C for steel. In alternative to furnace heating, induction heating allows to provide heat more quickly and more efficiently in forging applications; as a matter of fact, an high power density means extremely fast heating, as well as exacting control over the desired area. Moreover, this heating method is remarkably simple and cost-effective. In particular, the benefits associated to the utilization of this technology for forging are:

- Fast heating for higher productivity and volumes.
- Precise and uniform heating of only a portion or all the part.
- A non-contact, clean method of heating.
- Safety and reliability.
- Cost-effective, compared to other heating methods it allows to reduce the energy consumption.
- Easy to be integrated into production cells.

In hot forging, by mean of induction furnaces, induction heating is commonly exploited for the heating of metal billets and bar ends prior to forging operation (see **figure 5.32 and 5.33**). There are several critical issues that have to be considered when this process is adopted for forging:

- **Setting current frequency on the base of the size of the heated part:** not only the energy required to heat the part to the temperature desired for forging, but also the size of the part establishes the required current frequency of the induction system. As a matter of fact, working on an higher frequency than required, could damage the machine or the coil.

- **Time for complete heating:** the induction process causes the production of heat within the part, in particular, this heat is generated near the surface, therefore, it takes time to propagate to the core. This means that depending on the diameter of the billet, the time required for its uniform heating will be different (see **figure 5.33**). This time, is strictly affected by the physical properties of the material and must properly calculated, since over heating or under heating could cause the damage of the piece and/or the forging die.

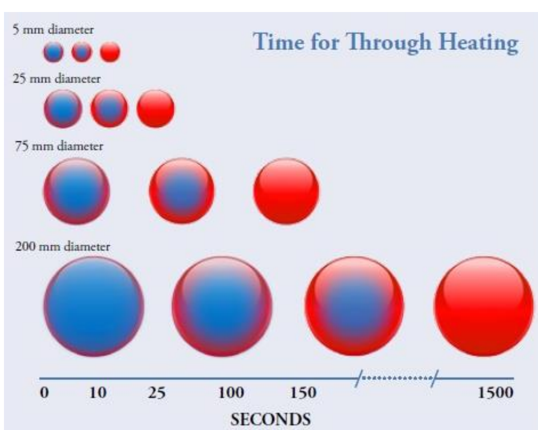

Figure 5.31

- **Avoiding radiation losses:** the loss of energy due to radiation from the incandescent part becomes important when the forging temperatures are reached (1000°C ÷1200°C for steel), it can be kept under control by a proper thermal insulation of the induction coil.

- **Ensuring proper coil cooling by using a water cooling circuit:** In the induction furnace the coils are exposed continuously to very high temperatures, that may lead to internal thermal stress and final failure. For this reason, a water cooling circuit is usually designed within the induction heater, in such a way to guarantee a longer life of the electro-magnetic coils.

Figure 5.32

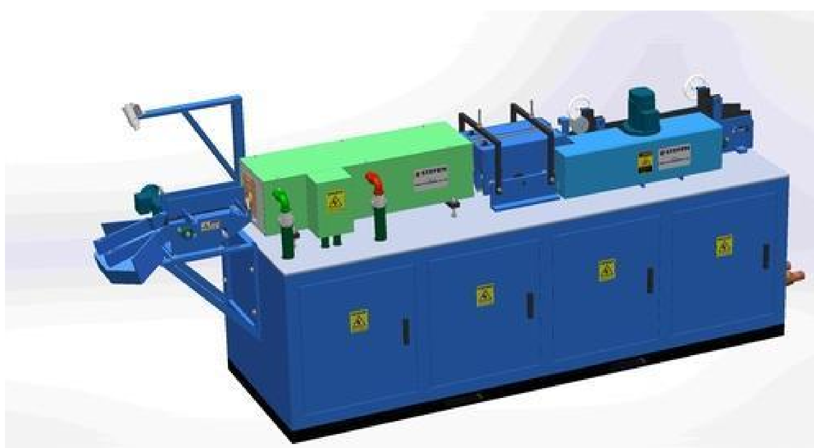

Figure 5.33

Figure 5.31 *Time for through heating as function of billet diameter.*

Figure 5.32 *An incandescent billet at induction furnace outlet.*

Figure 5.33 *Example of induction furnace used for the heating of billets prior to forging, from the right to the left: the pinch roll drive assembly, induction coils and discharge extractor conveyor.*

5.2.4 Forging equipment

The selection of forging equipment depends on a large number of factors, such as quality, material, size, and the complexity of the parts to be produced. Hot forgings are commonly produced on a different equipment, including presses and hammers. In particular, the forging equipment can be subdivided into two basic kinds: *stroke-restricted* and *work-restricted* machines.

In work-restricted machines, the energy or maximum force available limits the deformation that can be obtained during each stroke; if this energy or force is less than required to completely deform the part, then, more than one stroke is needed. Machines that belongs to this category are hammers, friction screw presses, and hydraulic presses.

In stroke-restricted machines, the stroke of the machine fixes the possible amount of deformation; if energy or force is insufficient to complete the operation, then, the machine risks the stall and a more powerful one should be used. Machines that belongs to this category are the mechanical presses, since is a crank that establishes the ram movement.

5.2.4.1 Hammers

Hammers are the most common types of machine adopted for hot forging, their basic technology was developed during the last century. This solution is usually preferred for small and medium batches because setups are faster and costs lower. Moreover, they are also used for the production of elongated and branch-type forgings, since dies areas are available for the larger number of preforming dies needed for these shapes. Eventually, mechanical presses with very high load capacities are not available, therefore, for the production of larger forgings is necessary to rely on large hydraulic presses or hammers. Let's make a brief overview of the most common solutions available:

- ***Gravity drop hammers:*** These hammers are the oldest kind of forging equipment available. During operation the moving die block (tup) is lifted up by a lifting mechanism and then released, in this way it falls on the static die that is fixed to the anvil. The amount of deformation available in this case is determined by the potential energy of the movable die block at its top position .When the die block falls, the potential energy is converted into kinetic one, therefore, it is dissipated in deformation of the part. On the market different types of lifting mechanisms are available, including frictional means with belts, chains, boards, or a lifting cylinder employing hydraulic fluid, compressed air or steam (see **figure 5.34**).

- ***Double Acting or Power Hammers:*** These kinds of solutions are similar to gravity hammers discussed previously, as matter of fact, a lifting cylinder lifts up the moving die block, but in this a case, also a lower moving die applies the power in order to increase the energy capacity. Energy ratings for equal tup weights are remarkably higher than gravity drop hammers, as well as the die closing speeds. Eventually, for this kind of machine the power is provided by double acting hydraulic, steam or compressed air cylinders.

- ***Vertical Counterblow Hammers:*** In these machines the double acting cylinders move two moving die blocks with almost equal masses toward each other in order to impact in the center of the machine, therefore, more energy is dissipated in the part.

- ***Horizontal Counterblow Hammers:*** In these kinds of hammers also called "impacters", during operation an automatic transfer mechanism places the heated billet vertically between the dies, then two double acting cylinders horizontally actuate two rams.

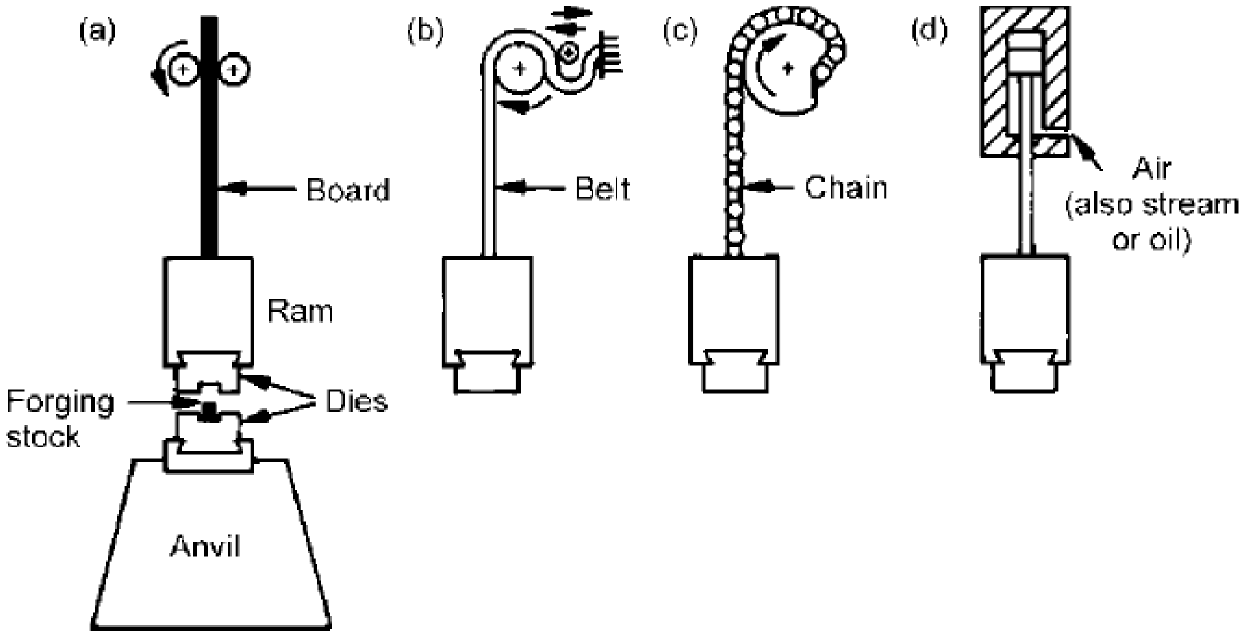

Figure 5.34 *Schematic representation of different types of drop hammers. (a) Board hammer. (b) Belt hammer. (c)Chain hammer. (d) Airlift hammer.*

5.2.4.2 Presses

Presses are the other common type of machines adopted for hot forging; Let's make a brief overview of the most common solutions available:

- ***Mechanical Presses:*** In this case a knuckle joint or crank is used to provide a vertical squeezing motion between the lower fixed die and the upper moving die. **Figures 5.35a** and **b** show typical mechanical press mechanisms. Generally, these kind of machines allow to get an improved die matching, since guidance of the two dies is more controlled than in hammers. On the market are available mechanical presses from 3 to 140 MN (300-14,000 tons).

- **Screw Presses:** In these kinds of presses the upper die and ram are connected to a vertical screw that is rotated by a flywheel, in such a way to move the ram up and down relatively to the die fixed in the bed of the machine (see **Figure 5.35c**). For each stroke a limited amount of energy is available, hence, similarly to hammers multiple strokes are usually used for forging. On the market are available screw presses from 0.63 to 63 MN (63-6300 tons).

- ***Hydraulic Presses*****:** In these machines the moving die is fixed to a ram driven by an hydraulic cylinder (see **Figure 5.35d**). In some cases these presses are also characterized by auxiliary horizontally moving rams, these ones allow the forging of side depressions into some parts. Several forces and closing speeds can be achieved on hydraulic presses, and different sizes are available on the market, the largest solutions can reach a load capacity of 50000 tons and even more.

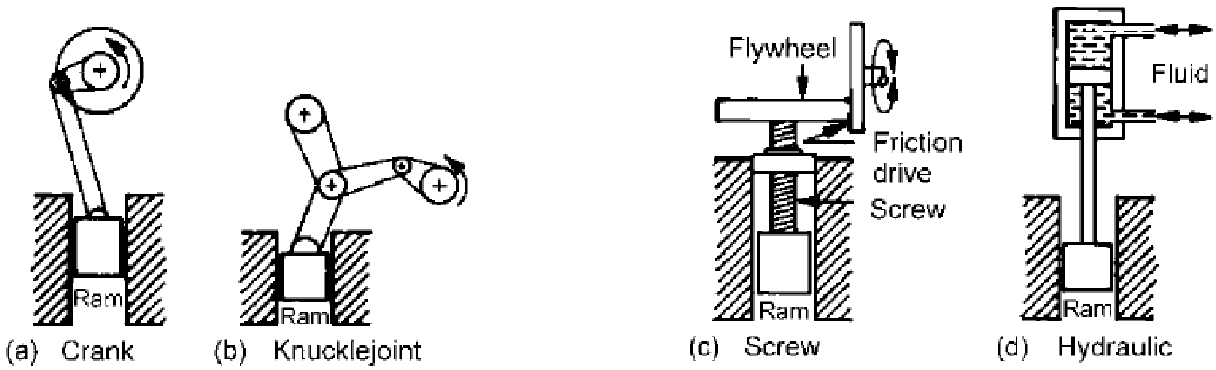

Figure 5.35 Schematic representation of various types of press mechanism used for forging. (a) Crank press. (b) Knuckle joint press. (c) Friction screw press. (d) Hydraulic press.

5.2.4.3 Choice of the type of forging machine

Even if it depends on a lot of factors, some guidelines for the choice between hammers and presses exist, In general:

- Branched and asymmetrical forgings usually need to be produced on hammers, since is required a total die area larger than that one available on mechanical presses with proper load capacity.
- Crank presses are particularly suitable for circular forgings in steel, until the dimension of these latters leads to excessive loads that make necessary the utilization of power or counterblow hammers.
- Blade-type forgings usually requires being forged using screw presses.
- It is more convenient to process smaller batch sizes on hammers rather than on presses, because setups are faster and costs lower.
- Hydraulic presses are more suitable for the production of thin-plate-type forgings characterized by edge ribs, and light alloy precision forgings.

- As already said, mechanical presses having load capacity above 14,000 tons are not usually available; hence, the production of large forgings requires hammers or hydraulic presses, and counterblow hammers or large hydraulic presses for largest parts.

- Let's define the "usable stroke rate" as the stroke rate that consider the time necessary to manipulate the part between impressions, therefore, is not the maximum stroke rate achievable from the machine. Mechanical presses show highest usable stroke rates for smaller parts, for this reason they are preferred when higher productivity (large batches) is required. For large parts this criteria is not anymore valid, in this case the usable stroke rate becomes comparable for the different types of machines, since the time required to manipulate the part becomes predominant.

5.2.4.4 The Mechanical Press (crank press): layout and working principle

This paragraph is aimed to describe the type of mechanical press (crank press) used by ATB for the forging of raw parts, paying particular attention to the machine layout and working principle. The crank press, is a mechanical press where crank mechanism is used to provide a vertical reciprocating motion between the lower fixed die and the upper moving die (see **figure 5.36**).

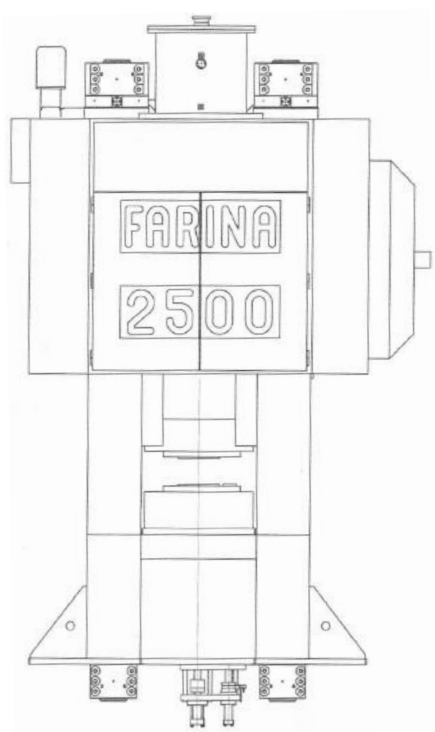

Figure 5.36 *Farina GAS 2500 tons.*

The main elements of the machine layout are: the flywheel; the electric motor driving the flywheel; the structure; the crankshaft; the ram; the connecting rod, that connects the ram to crankshaft, the clutch performing the frictional coupling, and the brake that stops the crankshaft to rotate (see **figure 5.37**).

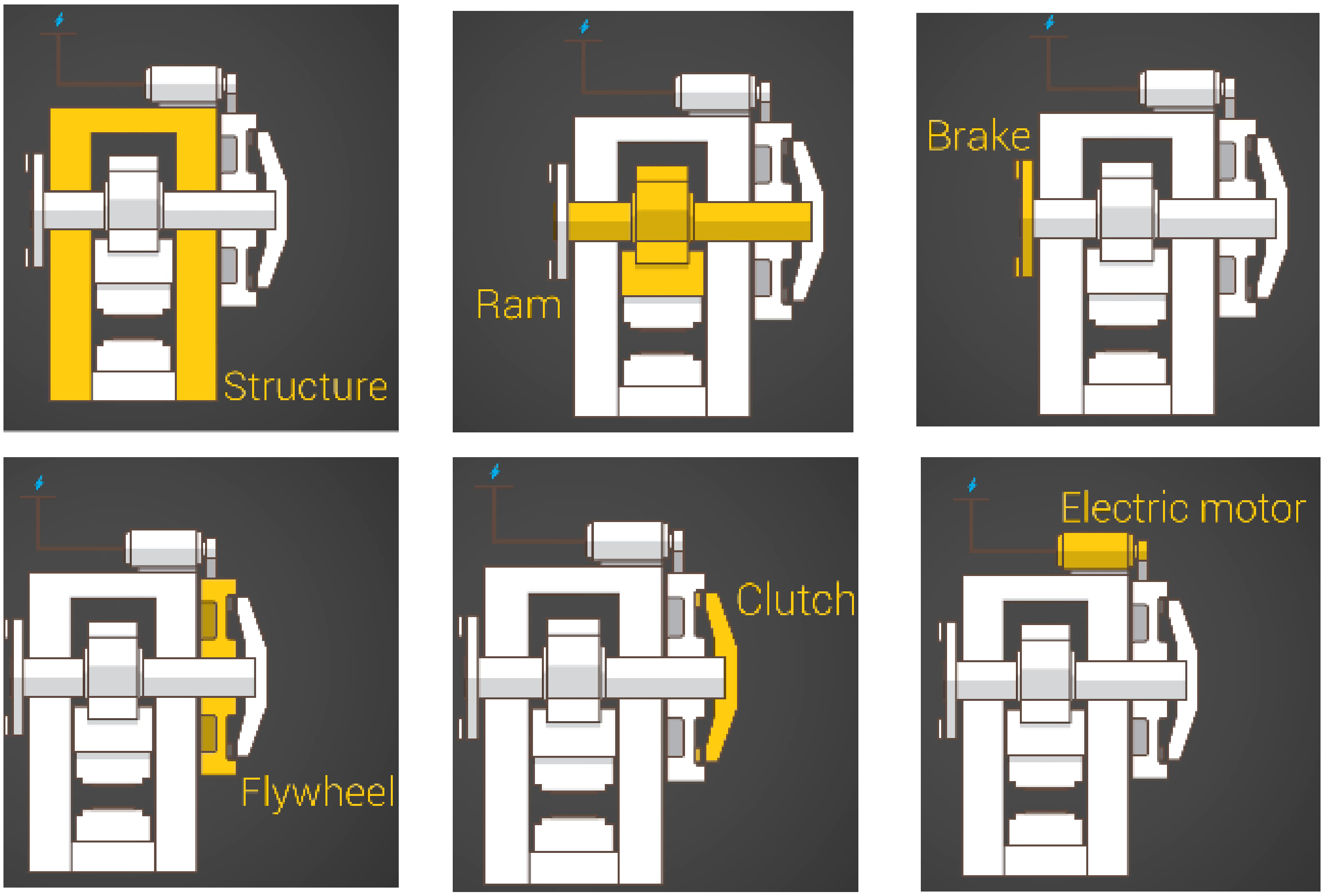

Figure 5.37 *The main elements of machine layout.*

The upper die is fixed to the ram, while the lower die is bolted on the working table of the machine. During the operating cycle, the mechanical power of the electric motor is transmitted to the crankshaft through the transmission system, in this way the crankshaft can rotate. The ram is connected to the crankshaft by mean of a connecting rod; therefore, it reciprocates squeezing the hot billet positioned in the lower die. The positioning of the part from one die impression to the next one occurs by hand or by mean of a manipulator robot.

In particular, once that the clutch is closed (start of the working cycle), the frictional coupling is realized; therefore, the electric motor drives the crankshaft to rotate through the pinion, the big flywheel and the clutch, then the ram carries out a reciprocating motion within the guide rail of the press structure (see **figure 5.38**).

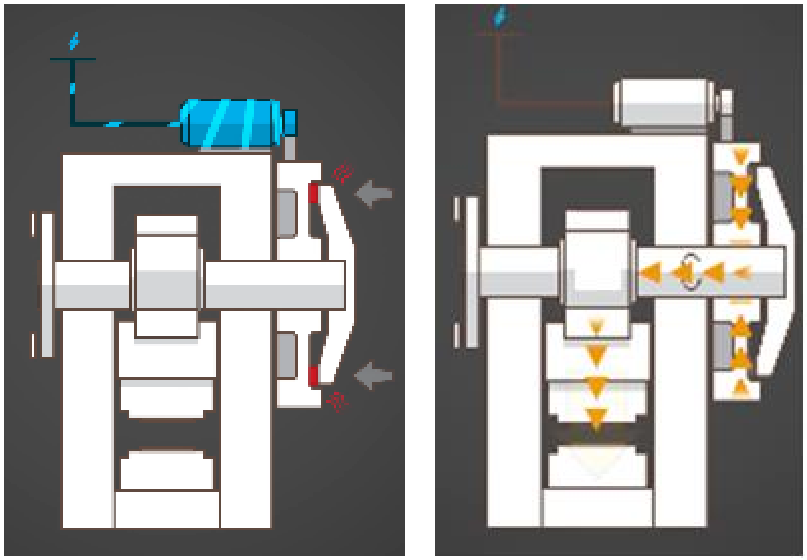

Figure 5.38 *Start of the working cycle.*

The clutch is closed by the foot pedal through the control system, in order to realize the movement of the crank mechanism. The brake, that is matched with the clutch, stops the ram at the top dead center (end of the working cycle) after that the clutch is disengaged (see.**figure 5.39**).

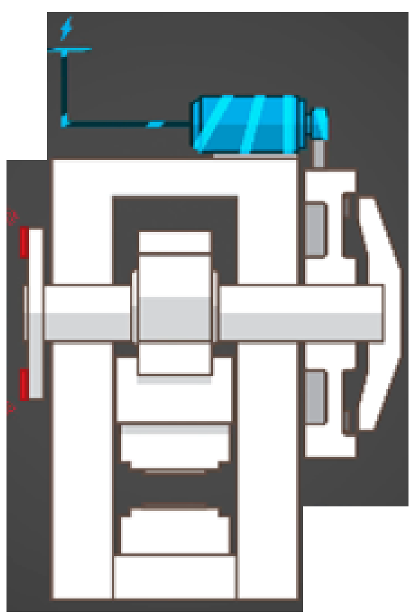

Figure 5.39 *End of the working cycle*

5.2.5 Finite elements process simulation

The development of this design tool for forging started at the end of 70's, during that time the automatic meshing was not present, for this reason a lot of time was required just to accomplish a simple finite elements simulation. However, the improvement of computational capacity and the development of remeshing methods have brought the finite elements simulation practical also for industrial purposes. Today, commercial finite elements simulation software are widely used in the forging industry (like in ATB for example), becoming integral part of forging design process due to the important advantages that can provide. The main objectives in closed die forging are to:

- Develop a proper die design by forging process simulation in order to ensure the correct die filling; prevent defects induced by the material flow as metal folds; predict process thresholds that must not be exceeded to avoid internal and surface defects; predict the temperature at any instant of time to control material properties, friction and die wear.

- Improve the part quality and performance cutting at the same time production costs by reducing lead time, scrap material and die tests.

- Predict the forging load in order to avoid the premature die failure and select the proper forging machine.

Performing experiments and tests is time consuming and expensive, from this point of view, for the forging design process, the finite elements process simulation results very advantageous. As a matter of fact, once the part is designed for the forging process, the die design is carried out through the following steps:

1. Perform a preliminary die design by resorting to experience based knowledge.

2. Verify the initial die design and forging process variables by resorting to a finite elements process simulation. In this case it is suggested to use one of the well consolidated finite elements simulation software commercially available, together to a computer with a good computational capability.

3. Modify the initial die design and process variables selected, on the base of the results obtained from process simulation.

4. Complete the die design and proceed with the generation of the dies.

5. Conduct die tests on the forging equipment.

6. Modify the last die design and process variables selected, and to produce some proof parts. Usually, at this step little or no modification is necessary, since process simulation is expected to be accurate enough to make all the changes needed before the dies generation.

5.2.5.1 Process simulation Inputs and Outputs

The main inputs required for the process simulation are:

- *Geometric Parameters:* the initial die and part geometry are required to be defined in a closed die forging *s*imulation. Depending on the geometry complexity, the process can be simulated either as three dimensional or two dimensional problem. Obviously, if the process involves more than one die impression, the die geometry of each one has to be provided.

- *Process Parameters:* the typical ones considered in closed die forging include the die, billet and environmental temperatures, the heat transfer coefficients between dies and billets, the time required to move the hot billet from the furnace to the die, the friction coefficient at the die and part interface, and so on.

- *Material Parameters:* a closed die hot forging simulation is both a heat transfer and deformation simulation, for this reason, all the material parameters referred both to deformation and to heat transfer require to be defined. The most common material parameters adopted for heat transfer are the emissivity, the heat capacity, the thermal conductivity of the part and die materials. In particular, they are usually expressed as a function of temperature. Instead, the most common material parameters defined for the deformation are the Poisson's ratio and The Young's modulus (as a function of temperature), and the thermal expansion coefficient of the die materials.

The process simulation provides very important informations about the forging process. The main outputs usually provided are the history and distribution of state variables (such as the temperatures, strain rate, and strain), the metal flow, the forging microstructure and the equipment response during the process.

The information about the metal flow is very important for design purposes, as a matter of fact, an improper metal flow is responsible of defects in the forging. Without any simulation software, it is necessary to wait for the completion of the forging process before to check if defects are present on the part. Instead, the big advantage of a computer forging simulation is that the entire forging process can be monitored, therefore, it is preventively possible to foresee if and how a defect formed before the actual forging (see **figure 5.40**). This means that the formation of defects such as metal folds can be eliminated changing the geometry of the die, or the geometry of the workpiece (preform or billet), or both. In this case, the software can again put into evidence if the corrective action is effective or not.

As said, the process simulation also provides as ouput the equipment response. A typical example of equipment response is the forging load: during the forging operation the contact area between the workpiece and the dies increases bringing to an increase of the forging load. For this reason, it has to be monitored, in such a way to avoid any premature failure of the die.

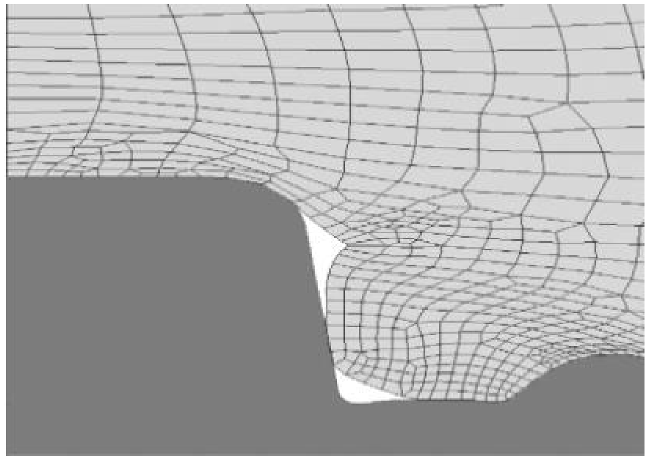

Figure 5.40 *Prevision of metal fold formation*

5.2.5.2 Other aspects

As we already know, during the forging process, the billet undergoes an important plastic deformation, and also the relative motion between the die surface and the deforming metal is significant. In the simulation of this process, the starting mesh is well defined and its density distribution can be chosen. From this point of view, the problem is that the mesh tends to get distorted as the simulation proceed. This question has been solved incorporating automated mesh generation (AMG) functions in the commercial finite elements codes for forging simulations; in particular, these functions generate a new mesh and allow to obtain accurate results interpolating the data from the new mesh to the old one.

Eventually, another important aspect which deserves to be mentioned is the time required to run the simulation: it depends at first on the computer used (especially the kind of processor and graphic card), but also on the workload and memory disposable. However, the computers of today make possible to run a two dimensional simulation in around a couple of hours, and a three dimensional simulation in one day or more depending on the geometrical complexity of the part.

5.2.6 3D laser scanner

With the term “reverse engineering” we mean the process of building from a real physical object an identic three-dimensional model, which can be used for some applications like manufacturing. The digital reconstruction of a surface requires the acquisition of a considerable number of points, for this purpose is used a 3D scanner. A 3D scanner is a device that collects informations about the shape (also color sometime) of an object, in such a way to produce its three-dimensional digital model. On the market there are several technologies for the digital acquisition of an object shape, in particular, according to a well-established classification is possible to talk about contact and non-contact three-dimensional scanners.

3D contact scanners usually operate on a fixed platform, and are characterized by a probe, which is mounted on a mechanical arm. In particular, the arm can be moved manually or robotically over the surface of the part; each time that the probe touches the object the scanner records its position as coordinates X,Y and Z. All the recorded surface positions form together a points cloud that can be used later for the calculation of the triangular mesh. An example of 3D contact scanner is given by the Coordinate Measuring Machine (CMM) as in **figure 5.41**, it allows to measure the geometrical features of an object and it commonly used by manufacturers to inspect the parts produced. This kind of machine can be controlled manually by the operator (by hands or a joystick) or by a computer connected to it. The big disadvantage of these solutions is given by the fact that the contact between the probe and the object’s surface scanned could modify or damage it, this becomes truer considering delicate parts. Eventually, these kind of machines are slow if compared to non-contact 3D scanners.

In non-contact 3D scanners there is not any physical contact with the surface of the part scanned; these kind of scanners, in fact , rely on some active or passive methods to scan the object. Generally, are defined as “active”, the systems that project an artificial form of energy on the part analyzed (as ultrasounds, light, laser and other type of radiations for example). Instead, are defined as “passive”, the systems that exploit the natural light. As the previous case, the final result is a point cloud defining the body’s geometry.

Figure 5.41 *CMM (Coordinate Measuring Machine)*

Let’s focus now our attention on non-contact active scanners, in particular on 3D laser scanners. In general, these machines emit a laser and detect its reflection is such a way to scan the object desired. Depending on the laser-scanning technique adopted, is possible to divide theme into three different categories: laser triangulation, phase shift and time to flight. In particular, the 3D laser scanner used in ATB belongs to the first category.

The system is characterized essentially by a laser source and a camera, the source emits a laser on the part and the camera detects the position of the laser dot (see **figure 5.42**). The technique is called “triangulation” because the source, the laser dot and the camera can be meant as the three vertexes of a triangle. The distance between the camera and source is fixed, therefore, one side of the triangle is known. Moreover, the angle corresponding to the laser source corner is also known, while, the angle corresponding to the camera corner can be determined. This means that by these three informations is possible to compute the geometry of the triangle, therefore, is possible to determine the position of the laser dot. Eventually, all the recorded surface positions form together a point cloud that can be used later for the calculation of the triangular mesh, therefore, is possible to reconstruct the three-dimensional digital model of the part scanned. We have to notice, that in many cases (as occur for the ATB’s laser scanner), the source emits a laser stripe over the part instead of a laser dot, in such a way to accelerate the scanning process.

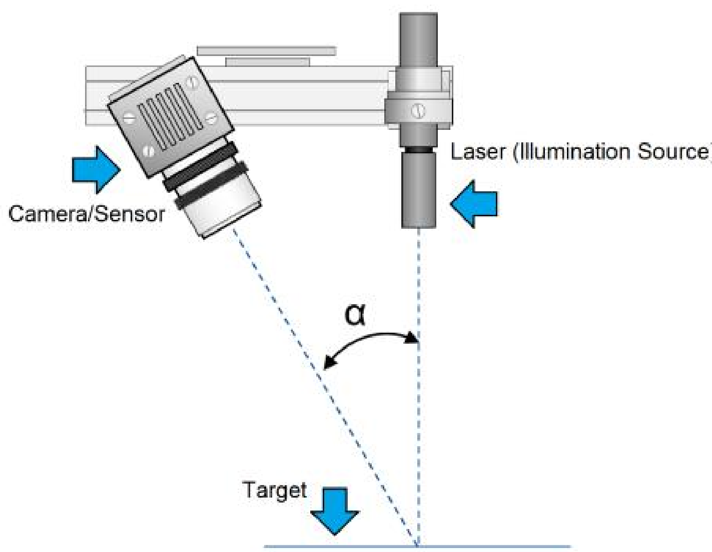

Figure 5.42 *Laser triangulation system*

The operator that means to carry out a process of reverse engineering has to face two different phases: the data acquisition by a 3D scanner system and the digital reconstruction of the object’s surface by a computer. Therefore, the software is essentially used to convert the points acquired, expressed under form of spatial coordinates, in a digital surface that is close to the real one. Hence, let’s discuss now which are the phases that the operator has to perform by a proper software, in order to obtain the three dimensional digital model of the object:

1. *Import of the point cloud:* the file containing the component's coordinates is generally expressed in ASCII format. Therefore, the file is a simple text file that the software can convert graphically in a point cloud that represents the shape of the part. If for example the scanning has been performed with a 3D laser scanner, the number of points imported can reach the hundreds of thousands also for an object of small dimensions. Therefore, a preliminary filtering phase is necessary for the elimination of all the errors.

2. *Polygonize of the cloud as triangular mesh*: in practice by software the points are joined together through small surfaces, generally triangles, in order to obtain a first preliminary surface that approximates the real one. During this phase is important to eliminate every single hole in the surface and any overlapped polygon. The meshed surface so obtained is usually referred with the name of "Shell" and is exported as an STL file.

3. *Conversion of the Shell into NURBS surfaces*: at first, by software are traced the curves (called "spline" curves) that join in sequence the vertexes of the triangles, in this way is obtained a grid (called "Network") on which are positioned the final surfaces. At this point, the digital reconstruction of the object's surface occurs in two steps. During the first one, the software generates a set of temporary surfaces (called "springs") that lay on the spline curves previously created. On these surfaces are eventually mounted the final NURBS surfaces. We have to notice that the surfaces so reconstructed does not have a continuous aspect, but well approximate the reality (see **figure 5.43**).

4. Once that the digital reconstruction of the object's surface is completed, the file can be exported in a CAD software.

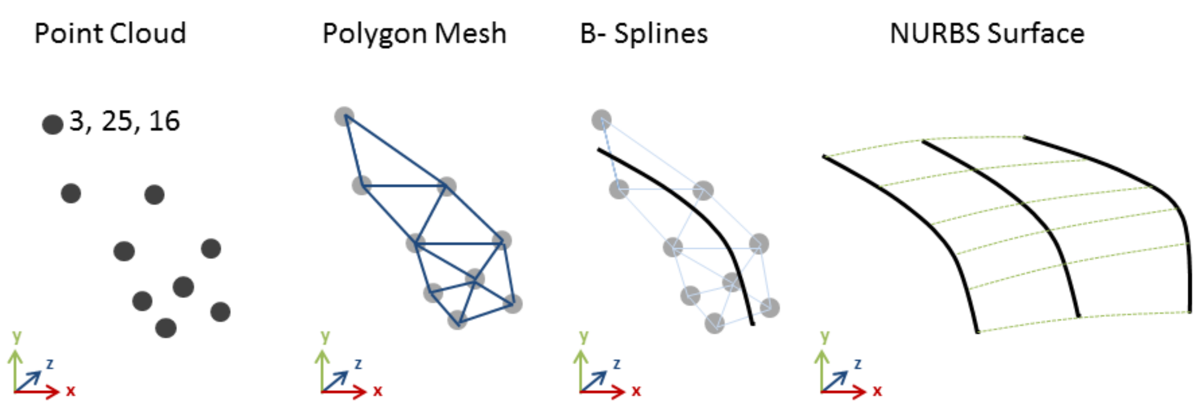

Figure 5.43 *The digital reconstruction of the object's surface*

The 3D laser scanner, as already mentioned in the paragraph 5.2.1, is a powerful tool to improve the die design. In particular, in ATB, it is used for the tuning of the die*:* it consists in the casting of special Pb alloy (having higher density and lower melting temperature than steel) inside the die, the sample part obtained it is subsequently scanned by mean of a manual 3D laser scanner GOM, in order to obtain a 3D digital model through a process of reverse engineering discussed before. Then, the 3D model achieved is superposed by a CAD software to the original CAD (the Zero) of the part, in such a way to put into evidence the areas in defect or excess of material (see **figure 5.44**). The areas in red put into evidence the regions with excess of material, while the areas in blue put into evidence the regions with defect of material. Therefore, the die design is modified in order to get the optimal forging condition.

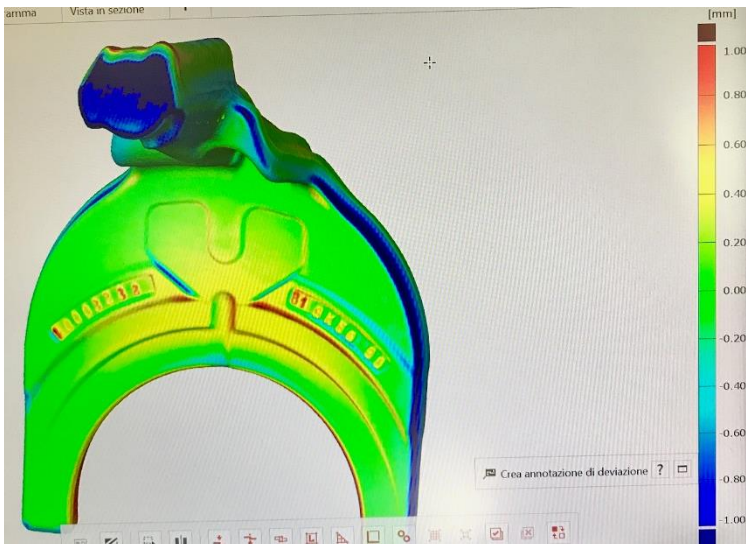

Figure 5.44 *Dimensional comparation activity*

5.2.7 Non-Destructive Testing (NDT)

5.2.7.1 Introduction

The role of Non-Destructive Testing is fundamental in industry; in fact, cracks and more in general defects can have a devastating effect on the performance of components and structures, for this reason, their identification is an essential part of quality control in all fields of engineering. The crack can be defined as a discontinuity originated by inter or trans-crystalline detachment in an originally continuous metallic material. With the term "Non-destructive Testing" (NDT) we mean the set of physical tests which are intended to investigate the possible presence of defects in a piece, without the necessity to destroy it, thus making it unusable.

Among the NDT techniques, we can distinguish the radiographic methods, the ultrasonic ones, the inspection with penetrating liquids, the method of magnetic particles (magnetoscopy), the thermography, the techniques based on the use of electric and magnetic fields and the visual inspection.

In industry, the NDT techniques are applied to both metallic and non-metallic materials and to objects of different sizes, both static and moving; but there is a point common to all, namely their ability to not influence in any way the physical-mechanical characteristics of the tested component. This means that, differently from many of the tests usually used to characterize the materials (for example the tensile test) that are responsible of partial or total destruction of the specimen, the non-destructive tests do not affect the functionality of the part. Therefore, it is possible to put it again in operation (when it is not possible to test it "in situ") immediately after performing the test.

The existence of a considerable variety of NDT methods suggests that no one of the techniques disposable is complete, but rather that they constitute a set in which each one is more suitable than the others in certain circumstances. Moreover, as often happens, more methods are employed together for the testing of the same part, in order to ensure the identification of as many potential defects as possible.

Generally, the various methods are classified by distinguishing the "volumetric" from the "superficial" ones: the first ones (x-rays and ultrasound) make possible to identify defects inside the component, while the second ones (magnetoscopy, penetrating, induced currents and visual inspection) make possible to identify surface or sub-surface defects. Sometimes, as happens for example in the case of the ultrasonic method, by adopting appropriate precautions, it is possible to detect both the types of defects, but in general this technique is mainly used for internal testing.

Another important factor is the type of material tested. Not all methods are appropriate for investigating any material used in the various sectors of mechanical, civil or nuclear engineering. For example, the methods of magnetic particles and induced currents can be applied respectively only to ferromagnetic or conductive materials, therefore, they are not suitable for plastic and rubbery non-metallic materials. Instead, this problem does not result if ultrasounds are used, since being elastic waves, require only a medium (solid or liquid) within which to propagate.

5.2.7.2 The Magnetoscopy: working principle and steps of execution.

The technique adopted in ATB to investigate the possible presence of defects in a part is the method of magnetic particles, let’s focus now our attention on this particular strategy.

The Magnetic Particles Inspection (MPI) also called "Magnetoscopy" is a non-destructive investigation technique very common in the automotive, petrochemical and aerospace industry; it exploits the ferromagnetic properties of the materials to highlight discontinuities on the tested part. Therefore, the only essential requirement to perform this type of control is that the component is composed of ferromagnetic material (such as iron, nickel, cobalt and some of their alloys).

These types of materials are strongly influenced by external magnetic fields; in fact, they are attracted by them and are also able to maintain the magnetic properties even after that the magnetic field has been removed; therefore, ferromagnetic materials have the characteristic of being able to be magnetized with the aid of an appropriate instrumentation.

Essentially, the Magnetoscopy resorts to a magnetic field and tiny particles of ferromagnetic material (such as iron) to identify the presence of defects in the tested components. The basic principle of the method is relatively simple: it is known that when a magnetic bar is broken into two parts, two new complete magnets originates and have N and S poles on the ends, in which respectively the lines of force of the magnetic field have origin and end. On the other hand, if the initial magnet is not completely cut, but only partially interrupted (as in the case of a crack), the two new poles are created in correspondence of the region in which the material is absent. In this situation, if small metal particles are introduced above the system, these latters will be attracted not only to the two ends of the original bar, but also to those of the crack. Therefore, the first step to perform an MP inspection is to magnetize the component to be tested. The presence of defects on the surface (or immediately below), will result in a loss of magnetic field. After the magnetization phase, the piece is subsequently sprinkled with very fine magnetic particles (either in dry form or in liquid suspension) which are attracted and aggregate in the area of the field loss, in such a way to form an indication clearly visible of the presence of cracks or other defects (see **figure 5.45**).

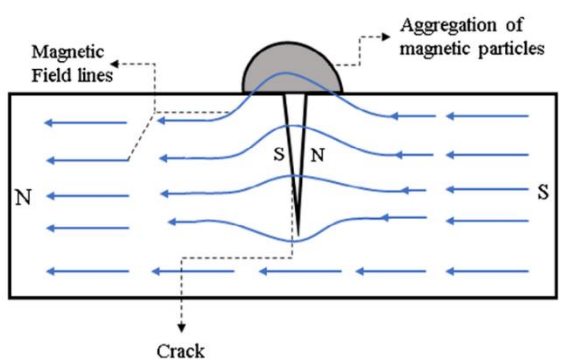

Figure 5.45 *Aggregation of magnetic particles at the borders of the discontinuity*

Let's discuss now, more in detail, the different phases that has to be executed in order to perform the MPI:

1. *Surface preparation*: In this phase, it is necessary to verify if the surface of the piece to be tested is sufficiently free from the presence of grease and dust, in such a way to allow the magnetic particles to move freely and concentrate in the regions where there is a loss of magnetic flow.

2. *Surface magnetization*: In general, it is possible to resort to two different types of magnetic fields. longitudinal magnetic fields, having lines of force parallel to each other and that originate and terminate in the poles of the magnet (or electromagnet) used for the inspection. Circular magnetic fields, in which the lines of force run in a circumferential direction around the perimeter of the tested component (see **figure 5.46**). A magnetic field like this can be generated, for example, by making to pass a current through the component. The resulting type of magnetic field is determined by the kind of instrumentation used to perform the inspection.

Figure 5.46 *Longitudinal and circular magnetic field*

It is very important to be able to magnetize the piece in two directions because, when the angle between the direction of the magnetic field lines and the prevalent defect dimension is very high (between 45 and 90 °), the defects are more easily detectable. In fact, at 90° (optimal condition) the greatest dispersion (flux leakage) of the lines of force of the field is obtained, while, when the magnetic field lines are parallel to the direction of the defect, there could be insufficient dispersion to produce visible indications (see **figure 5.47**). So, since the defects can occur with random orientations, each part is usually magnetized in two mutually orthogonal directions.

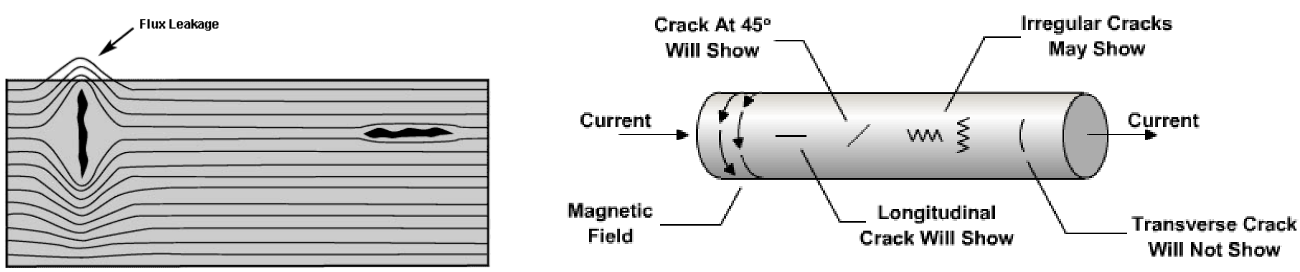

Figure 5.47 *influence of the direction of magnetic field and defect on flux leakage*

The magnetization of the piece can be performed by electrical systems (based on the direct passage of current through the piece to be tested) or magnetic ones (which exploit the action of a magnetic field generated in a second conductor closely placed). The machine used in ATB belongs to the second type of systems, in particular, it uses a coil which is moved above the piece to be tested. The passage of current in the coil generates a very strong magnetic field in the area between the two tips that hold the piece in position (see **figure 5.48**).

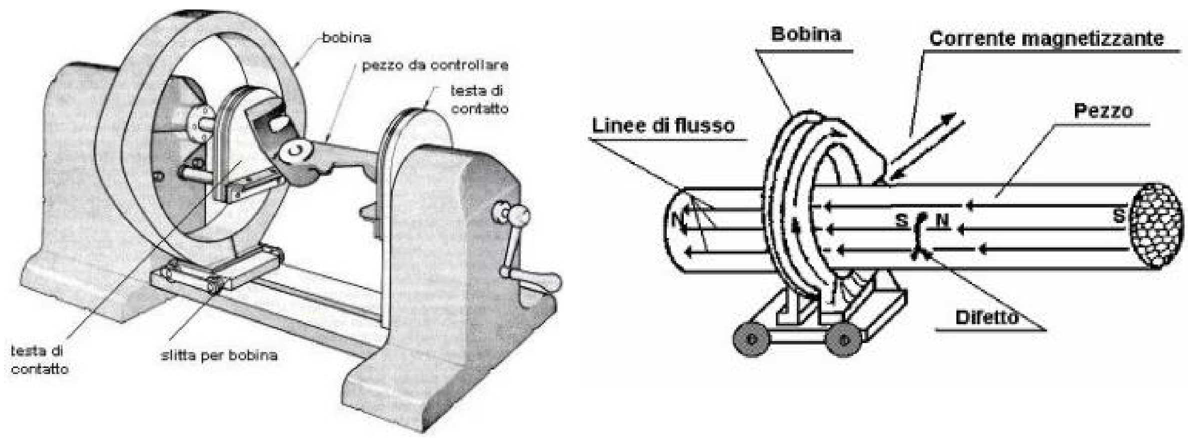

Figure 5.48 *Magnetic system for the magnetization of the piece used in ATB.*

3. *Magnetic powder application*: the magnetic powders used for MP inspections are the key element for the success of the examination, since they arrange in such a way as to make the presence of the discontinuity visible to the operator. The base material for powders is usually iron filing (or iron oxide) which can be pigmented to increase the contrast on some types of surface.
   From an operational point of view, is possible to distinguish two main classes of powders: dry and wet. The dry magnetic powders are commercially available in red, blue, gray and yellow colors, in order to guarantee the maximum level of contrast between the powder itself and the background. Wet magnetic powders, instead, are suspended in a liquid medium having aqueous or oily base (typically a hydrocarbon); in particular, aqueous suspensions produce quick indications, are cheaper, do not involve fire risks and are easy to remove once that the examination has been performed. In general, an anti-corrosion agent is also introduced into the suspension, although the kerosene suspensions are certainly superior in avoiding the risks deriving from this phenomenon. Eventually, the use of these powders allows the easy application on relatively large areas and also the possibility of coating the granules with fluorescent pigments.

4. *Surface illumination:* to analyze the result of the MPI, it is necessary to have a good level of illumination that can be achieved by resorting to fluorescent (80W) or incandescent lamps at a distance of 1 meter from the piece. For tests performed with fluorescent powders, is indispensable the use of a so-called "black light" lamp, that is a device that emits ultraviolet light in the wavelength band 320-400 nm. When this type of light source is used, is necessary to keep in mind that it is affected by the presence of a magnetic field, therefore, you must keep the lamp away from the magnetizing equipment. Furthermore, frequent consecutive switching on and off must be avoided, since they significantly shorten the life of the lamp.

5. *Surface inspection*: the result of the inspection depends on the visual acuity and experience of the operator. In particular, surface defects tend to provide clear and well-defined indications, with particles well agglomerated together. In this case, a sort of accumulation of particles is clearly visible, that is as bigger as deeper is the defect. **Figure 5.49** here below, shows a defect identified on a piece inspected in ATB during the internship project.

Figure 5.49

6. *Demagnetization of the piece*: very often it is necessary to proceed with the demagnetization of the piece once the MPI has been performed. This can be done by applying a magnetic field of opposite polarity with respect to the previous one and gradually decreasing intensity.

6 Optimization activity

6.1 Introduction

As already discussed in the second chapter, The World Class Manufacturing is a methodology which has as objective the progressive improvement of productive activity performed by the enterprise, through the modification of the plant, the modification of work modalities and the optimization of procedures with the aim to reduce to zero wastes and losses. According to this approach, the activities of all teams are oriented to the realization of projects which goals are: zero wastes, zero defects, zero failures, zero incidents and zero buffer stock; for a general reduction of costs of the plant.

Motivated by this "way to think" oriented to the continuous improvement of production activity, the idea of ATB's managers was to pursuit the objective of production costs reduction acting at the beginning of the production process. Therefore, the main project entrusted to me during my experience in ATB was devoted to the reduction of the steel required for components production through the reduction of wastes due to the cut of the initial bars of steel. The activity was performed without affecting the standards of quality required by the clients. Hence, from this point of view, it was actually a WCM activity.

Now let's discuss more in detail, the strategy followed during the time spent in the forging plant of Forno Canavese to accomplish the project.

6.2 Activity of reduction of steel requirement

As we already seen in the paragraph 5.2.2, before the forging process, by cutting machine each one of the steel bars of length L (provided by the supplier) is cut in N billets of equal length l.

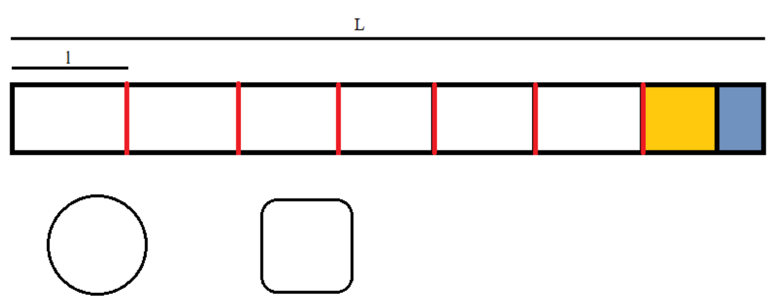

Figure 5.24

As put into evidence in **figure 5.24**, during this phase, part of the total starting material can be wasted in three different ways:

- Because of the thickness of the cutting blade (in red in the picture).
- Because of the portion of the bar required for clamping (in blue in the picture).
- Because of the scrap material due to the subdivision of the bar into billets of equal size (in yellow in the picture).

Therefore, the activity of reduction of steel requirement is aimed to limit these wastes as much as possible, by trying to maximize the percentage of use of the bar. This percentage was taken as a performance indicator; in fact, it suggests how we are exploiting the material disposable per each bar (well or badly). It can be expressed as follow:

$$\mathbf{n° \text{ of billets per bar}} = \frac{(\text{L bar} - \text{clamp length})}{(\text{l billet} + \text{cutting blade tickness})}$$

$$\mathbf{L \text{ useful bar (cut included)}} = (\text{l billet } + \text{cutting blade tickness}) * (\text{n° of billets per bar}) + (\text{clamp length})$$

$$\mathbf{\% \text{ of bar utilization}} = \frac{\text{L } useful\ bar\ (cut\ included)}{\text{L bar}}$$

The thickness of the cutting blade and portion of the bar required for clamping are fixed, therefore, there is no way to recover material wasted for these two reasons. This means that the unique source of waste that is possible to reduce, is the scrap material due to the subdivision of the bar into billets of equal size.

The first parameter on which is possible to play in such a way to optimize (maximize) the percentage of use of the bar, is the length of billets l. A hypothesis of length increment is useless: maybe, in some cases it could bring to an increase of the indicator, but the material recovered during the cutting phase would be wasted the same later, during the forging phase, under form of material in excess (flash). For this reason an hypothesis of length reduction is the only consistent option.

The second parameter that can be considered (but with a secondary priority) is the total length of the steel bars L. In this case is necessary to take into account that not always is possible to conjecture a reduction or an increment of the length, this because the supplier is generally disposable to accept requests of change that involves more than one product code (the code that identifies a particular kind of product, the first letters are referred to the client, while the figures to the drawing code). For example, if the change of the length of the initial steel bars, from 6000 mm to 4000 mm, involves just one product code among other six, it is expected that the supplier will not accept the request.

On the base of the previous considerations, the percentage of use of the bar can be re-written as follow:

$$\textbf{n° of billets per bar} = \frac{(\text{ new L bar} - \text{clamp length})}{(\text{l billet} - \text{billet reduction} + \text{cutting blade tickness})}$$

$$\textbf{L useful bar (cut included)} = (\text{l billet} - \text{billet reduction} + \text{cutting blade tickness}) * (\text{n° of billets per bar}) + \\ + (\text{clamp length})$$

$$\textbf{\% of bar utilization} = \frac{\text{L } useful\ bar\ (cut\ included)}{\text{new L bar}}$$

Therefore, the activity of reduction of steel requirement has been carried out for each active product code involved, through the following steps:

1. Hypothesis of length reduction of the billet (and hypothesis of variation of the bar length when possible) that determines the maximization of the percentage of use of the bar. For this first phase, a proper excel sheet to facilitate calculations was created, in which all the data referred to each product code are collected. A picture is shown here below in **figure 6.1**.

SPECIFICA TECNICA TIPO MATERIALE / S

CODICE PRODOTTO FINITO ATB	FABBISOGNO ATB - PESO SPEZZONE [kg]	FABBISOGNO ATB UNITARIO [kg]	QUANTITA' FIGURE STAMPO (Attrezzatura ATB)	PESO SBAVATO (Kg)	ROTTAME al TAGLIO UNITARIO [kg]	ROTTAME da BAVA ATB UNITARIO [kg]	% SBAVATO / FABB.	OTTIMIZZAZIONE FABB.	Lunghezza Barra Utile incluso taglio	Riduzione lunghezza	# SPEZZONI per BARRA	Lunghezza Barra Utile incluso taglio	NUOVA LUNGHEZZA BARRA	Percentuale utilizzo barra
DAIM0034	1,25	1,25	1	0,63	0,09	0,62	50%	X	5904	-2	27	3996,2	4000	99,9%
EAT1430	4,11	4,11	1	1,9	0,20	2,21	46%	X	5988	-8	27	5994,2	6000	99,9%
EAT1431	2,12	2,12	1	1,21	0,15	0,91	57%	X	5896	-3	34	5966,4	6000	99,4%
EAT1432	2,93	2,93	1	1,68	0,15	1,25	57%	X	5978	0	30	5978	6000	99,6%
EAT1433	6,94	6,94	1	2,44	0,50	4,50	35%	X	5873	-3	29	5988,4	6000	99,8%
EAT575	1,83	1,83	1	1,02	0,08	0,81	56%	X	5898	-3	32	5990	6000	99,8%

Figure 6.1

2. Forging process simulation by devoted finite elements simulation software. The simulation provides very important informations about the forging process. The main outputs usually provided are the history and distribution of state variables (such as the temperatures, strain rate, and strain), the metal flow, the forging microstructure and the equipment response during the process. The information about the metal flow is very important for design purposes, as a matter of fact, an improper metal flow is responsible of defects in the forging. For example in the **figure 6.2** is shown the formation of a metal fold as foreseen by software, in this case the hypothesis of billet reduction is not suitable, for this reason is useless to proceed with the next phases of investigation.

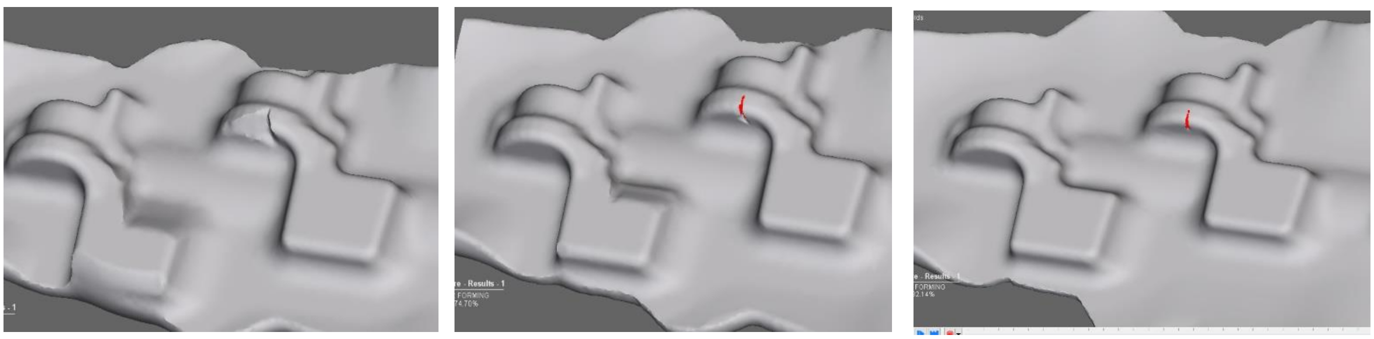

Figure 6.2 *Metal fold formation as foreseen by simulation software*

3. Physical test on the forging press with modified billets. As shown in **figure 6.3**, the billets used for the tests were reduced in length and marked with a lateral double groove by turning machine.

Figure 6.3

Moreover, the tests were performed producing three samples per each die impression, an example is shown in **figure 6.4**.

Figure 6.4 *Samples produced for testing*

We have notice that the handling of the workpiece between the different die impressions, the loading of the billet from the induction furnace to the forging press and the displacement of the forging from the forging press to the trimming one, can be performed by hands or by robot manipulators. In both the two cases was fundamental the support of a specialized team of operators to handle the material in dangerous conditions and to arrest and restart the machines in the desired steps of production. In particular as shown in **figure 6.5,** in the case of robotized machines was also necessary to investigate the correct grip and positioning of the material (billets, forgings and flash after trimming), since the tests were performed with the original set up and the robot are programmed to move the gripper in specific points in the space.

Figure 6.5 *Grip of the flash after trimming*

4. Sandblasting of the samples produced to clean the surfaces from residues ad impurities.

5. Magnetic Particles Inspection (MPI) of the samples to investigate the possible presence of defects in the parts as shown in the **figure 6.6** here below.

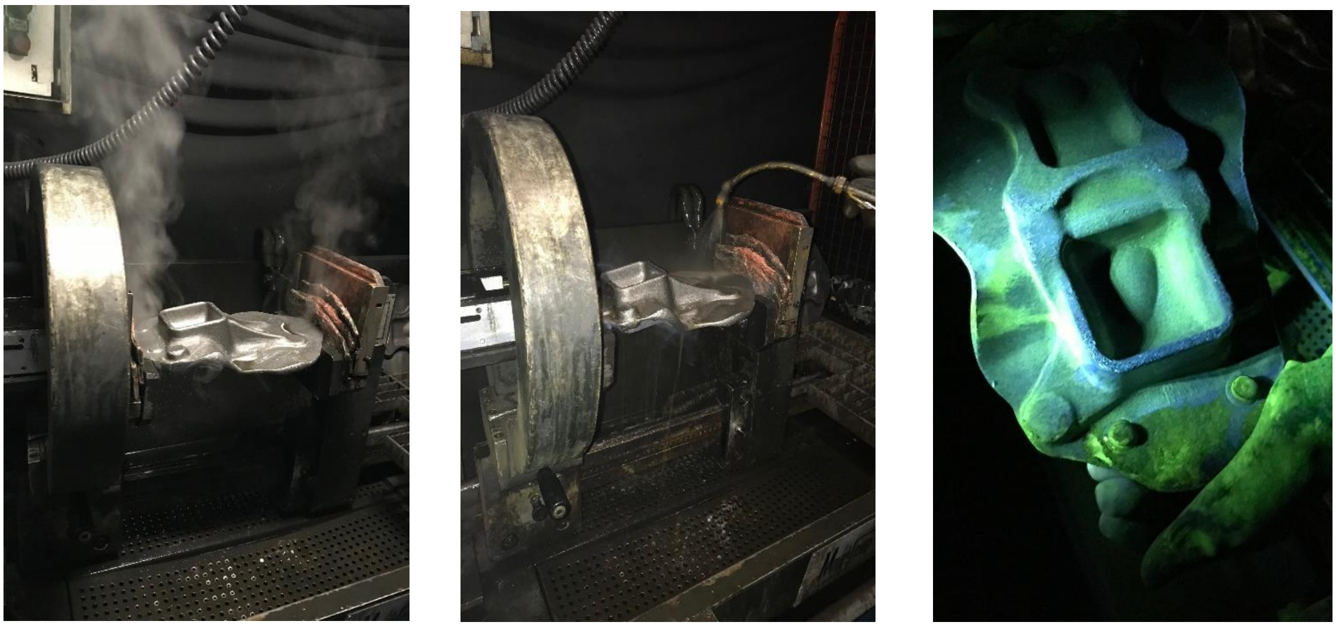

Figure 6.6 *MPI of the sample: respectively magnetization, magnetic powder application and surface inspection of the part*

6. Final visual comparison. During this final phase the samples are compared with the so called “green parts”, they represent the optimal forging solution. Therefore, if the samples’ details result equal to those of green parts the feasibility of the billet’s length reduction is confirmed.

Eventually, we have to notice that all the physical tests were carried out at end of dies’ lives, since in that particular moment the amount of material required for forging is the maximum one. Therefore, all the tests were performed putting ourselves in the worst operating condition possible. If the result of the test is positive in that particular operating condition, it is expected to be positive in all the other ones.

7 Conclusions

Even if ATB has not still obtained the bronze medal, it is already possible to understand the many benefits achievable following the guidelines given by WCM methodology. I got immediately this feeling in the Valperga Canavese plant, the one devoted to machining and assembly: the level of cleanness, order and organization reflects the spirit of the method; these features allow to increase remarkably the safety of personnel in the workplace, and to reduce wastes in terms of handling time.

From my personal experience, i can say that the method is actually effective. The implementation of the technical pillars brings to the improvement of the production activities through the solution of eventual problems, trying to prevent them and to reduce or eliminate the losses, wastes and failures. In this context, the managerial pillars support the first ones being involved in accountability, change of mentality, awareness and motivation of the personnel at each level of the hierarchical pyramid.

As a result of introduction of the method, the ATB employees appreciate the improvements related to safety and environment, workplace organization, improving of their skills, involvement and professional growth.

Hence, this internship allowed me to know this "way to think" oriented to the continuous improvement of the production activity and to appreciate its benefits. Moreover, it allowed me to understand better the many aspects and issues related to the forging technology, which is an historical pillar of the industrial reality of my territory (Canavese). Eventually, this experience was useful for a first real approach to the main technologies adopted in a plant of this kind for design, forging and quality control of the raw parts produced.

For what concerning the main project performed in ATB, it was successful: optimizing the percentage of use of the bar, for each of the twenty active product codes, it was estimated a saving of 113.800 € on around 5.000.000 € of steel required for the volume of production scheduled in 2020. In particular, during my period of internship were tested ten product codes, of which all returned positive results. This activity of reduction of wastes was carried out guaranteeing the standards of product quality requested by the clients, therefore, following the spirit of the WCM method.

The development of different skills was fundamental to improve the quality of the work done, such as:

- problem solving skills
- teamwork skills
- dialogue skills
- ability in managing and using the available tools
- organization skills

In this experience, i felt myself an integral part of the project, this element was really important to get the proper motivation, but the most important thing was surely the quality of interpersonal relationships and the collaboration of the personnel.

Thanksgivings

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