DIE MANUFACTURING PROCESS

THE BEST FLOW FROM IDEA TO DELIVERY

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Catalogue

Abstract

This thesis is the result of my six months internship at FCA Mirafiori Die Shop. The objective of my internship is to study current die engineering and manufacturing workflow and weak point elimination activities.

At the beginning of my internship, I attended a training period regarding all activities in stamping technology department, die engineering department and die manufacturing department, in order to understand the internal die development process, including die feasibility, die process, die design, die simulation, milling path design, machining, assembly, benchwork, try-out and quality control. Moreover, some basic knowledge of project management and validation method have been acquired.

After this period, I started to follow weak point elimination activities. I participated in some exhibitions and benchmark visits to find new technologies to make up our weak point.

Having acquired a panoramic vision of die manufacturing process and some thoughts for die manufacturing process improvement, I began my activities contained in this thesis.

Chapter 1 briefly introduces the main procedures of automotive production, the process of metal parts stamping, the stamping operations and classification of different automotive dies, in order to explain what we are talking about in this thesis.

Chapter 2 gives an overview of the complete die development process in FCA die shop at the beginning. And then describes each operation in detail, especially the manufacturing activities which is the focus of this thesis.

Chapter 3 indicates a weak point in current die manufacturing workflow and introduces three innovative technologies alternative in market which can be potential solutions.

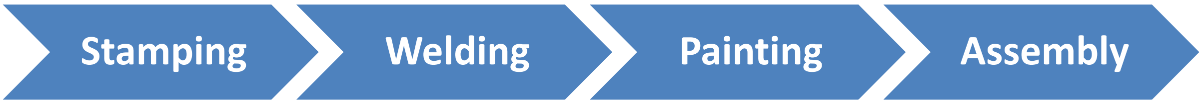
Chapter 4 further studies the technology we selected, including its components, its software, its installation, its benefits and introduces benchmarks of other die makers.

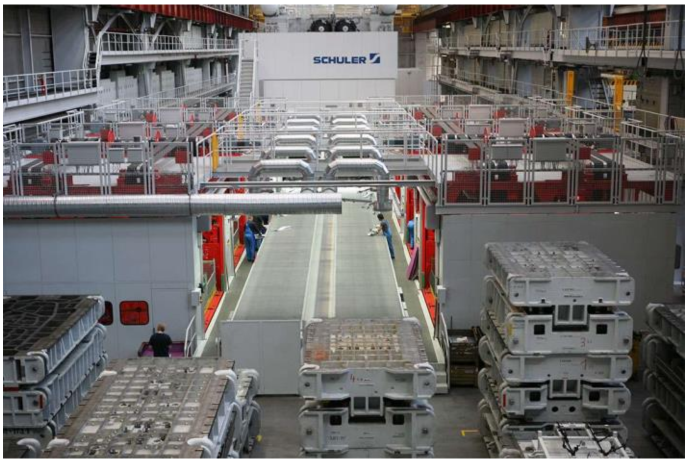
Chapter 5 shows the new die manufacturing process and new machining area lay-out after applying the technology we selected. Calculates the improvement of working time and manufacturing cost. Finally, makes a conclusion of the improvements for the complete die manufacturing process after using the selected new technology

Chapter 1 Introduction of automotive dies

1.1 Process of automotive production

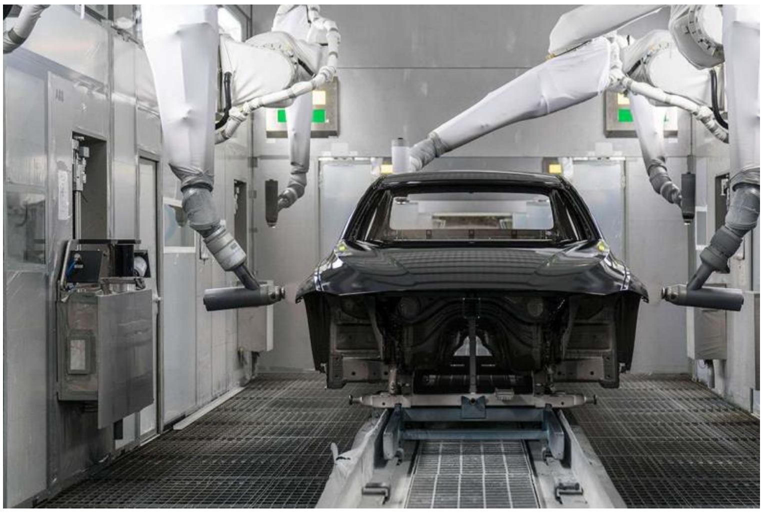
As a vehicle is produced in OEM, the production process has four main steps:





The stamping shop provides the sheet metal parts for the bodywork. Stamping is the process of placing flat sheet metal in either blank or coil form into a stamping press where a tool and die surface forms the metal into a net shape. The bands are initially cut to form boards and then pulled with the most modern, fully automated high-speed servo presses in several steps, forming and trimming. This results in molded parts such as body sides, doors, hoods and roofs.

The Welding shop joints together several hundred of individual parts made of steel and aluminum of different sizes and thickness to a precision body. With a highly automated welding techniques such as spot welding, soldering as well as the new laser welding. Most modern robots perform these serious and complex work with maximum precision.

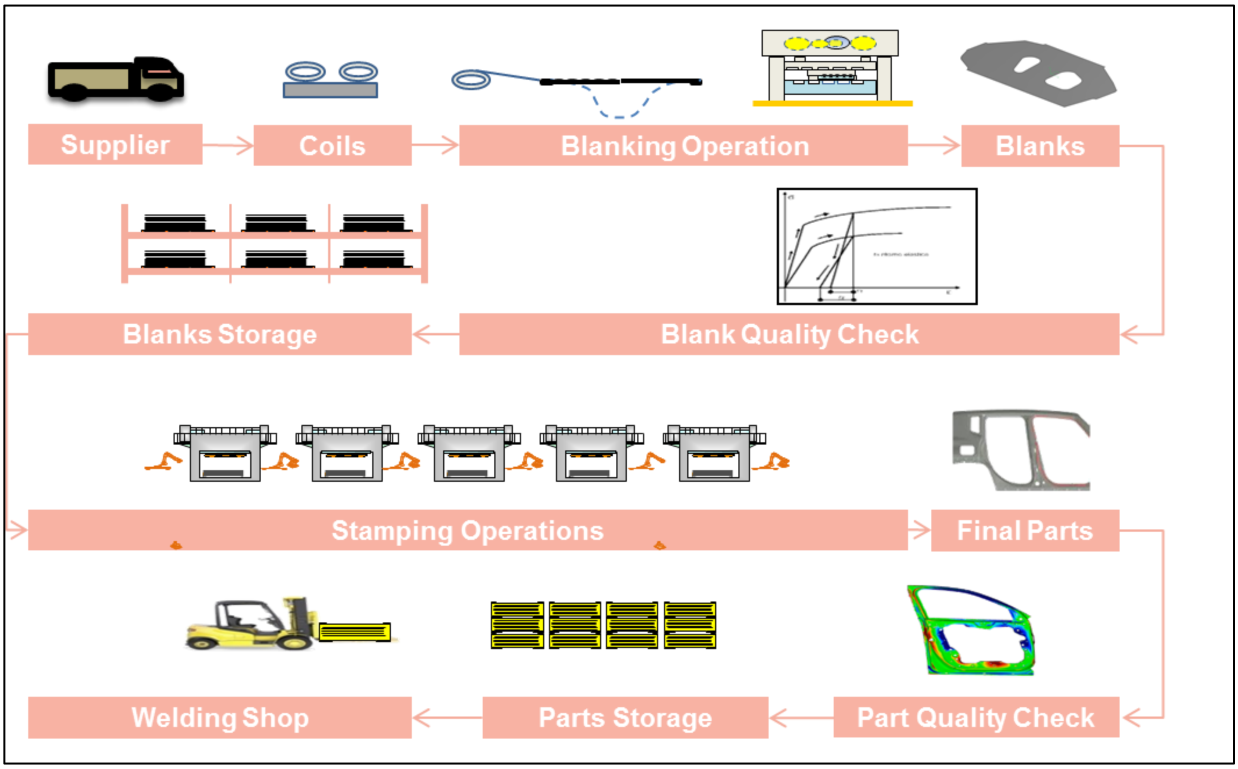


In the painting shop, the bodies are first cleaned in plunge pools and degreased, then coated with a zinc phosphate layer. This forms the basis for lasting corrosion protection. Then four more coats of paint, protect the vehicle against environmental influences and give a durable color gloss. Hardly a detail of an automobile acts so strongly on the senses like the color of the paint. At the same time it serves to protect and preserve the value of the automobile.

In the assembly shop, well-trained staff complete the painted bodies. In the course of individual production can be realized even unusual customer requests. Various equipment, attachments, country versions and more lead to the distinctive customized product. Within the final assembly the highlight of the entire production takes place, the so-called wedding. The drive unit of the engine, transmission and exhaust system meets precisely to the corresponding body and is screwed. Then vehicle is stationary on its own wheels. Last parts are mounted and the engine is started for the first time. After numerous tests the new vehicle rolls off the line.

In this thesis, we are only talking about stamping.

1.2 Process of metal stamping



The stamping shop receives metal blanks or coils from material suppliers. In FCA Mirafiori plant, due to the robot arm of blanking operation is magnetic which can only move steel sheets, the stamping process starts from shaped blanks for aluminum and coils for steel.

The first operation of stamping called OP10 is blanking. Metal sheet is cut into shaped blanks that is ready for successive forming process. And there will be a quality check for these blanks both on dimensions and material properties.

After the quality verification, blanks are able to send into press line. Several stamping operations are implemented to get the final parts. There will be another quality check for the stamped parts both on dimensional statistic control and aesthetic statistic control. And then, the metal parts are ready for welding.

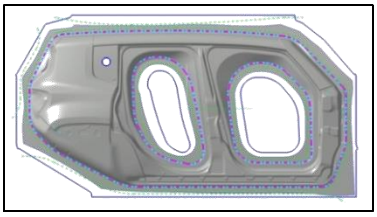
In this thesis, we are only talking about stamping operations and its dies.

1.3 Stamping operations

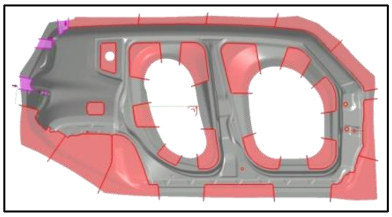
It is clear that a metal part with complex shapes cannot be obtained by a single stamping operation, therefore a sequence of multiple operations is required.

Stamping operations to be used for a specific part depend on its design and stamping equipment. However, normally the operations used extensively are blanking, drawing, trimming, piercing, restrike, flanging , hemming, etc. The first operation blanking prepares the initial approximate shape of the part in flat sheet. Then, drawing is generally the first operation to attain depth related form. Following operations piercing, flanging, hemming, are product design related operations. Trimming generally removes the extra material on the periphery of the panel provided for blank holding during draw operation.

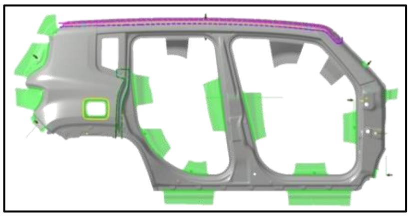
For example the stamping operations of the car body side:



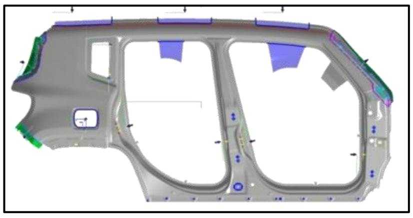
After OP20



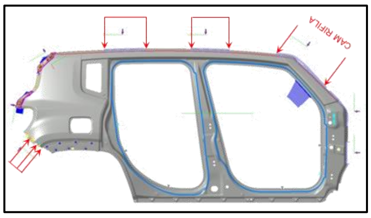
After OP30



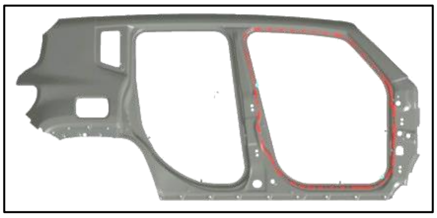
After OP40



After OP50



After OP60



After OP70 (final part)

1.4 Stamping dies

Die assures completion of all necessary operations to manufacture the component, starting from the sheet, which will be finally assembled on the car body. Multiple stamping operations require multiple dies.

By rule, the first OP10 has to be a notch and cutoff operation, OP20 a draw operation. Following operations are generally trim, flanging, restrike and piercing.

In metal forming, the geometry of the workpiece is established entirely or partially by the geometry of the die. In contrast to machining processes, significantly greater forces are necessary in forming. Due to the complexity of the parts, forming is often not carried out in a single operation. Depending on the geometry of the part, production is carried out in several operational steps via one or several production processes such as forming or blanking. One operation can also include several processes simultaneously.

The most common types of dies perform cutting and forming.

1.4.1 Cutting dies

Cutting dies are used to shear sheet material into what is called a blank. These blanks are then exposed to blanking dies which cut the entire perimeter of the part, or to forming dies where the blank is stamped into a part.

Trimming Die applied to perimeter areas, on which the Blank holder has previously operated (OP20). Trimming occurring on the vertical cutting plane (accordingly to the press movement), is implemented by blades fixed (usually) on the upper base. In case trimming has an horizontal component, usage of a CAM slides set would allow this operation.

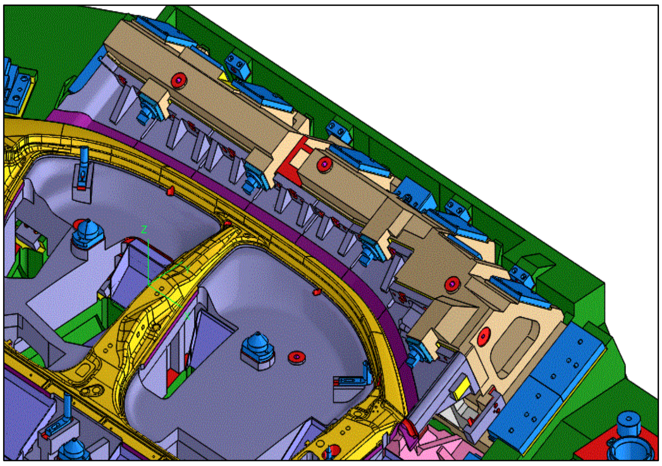


Figure: trimming die

Piercing Die allow to generate required holes. These should serve for example in fastenings, couplings, cable passages, flanging references, fluids and paint evacuation and so on. Holes are vertically generated, using appropriate punches for the upper base, where in lower base we find the relative die buttons. In case of flanged holes, a piercing CAM is required.

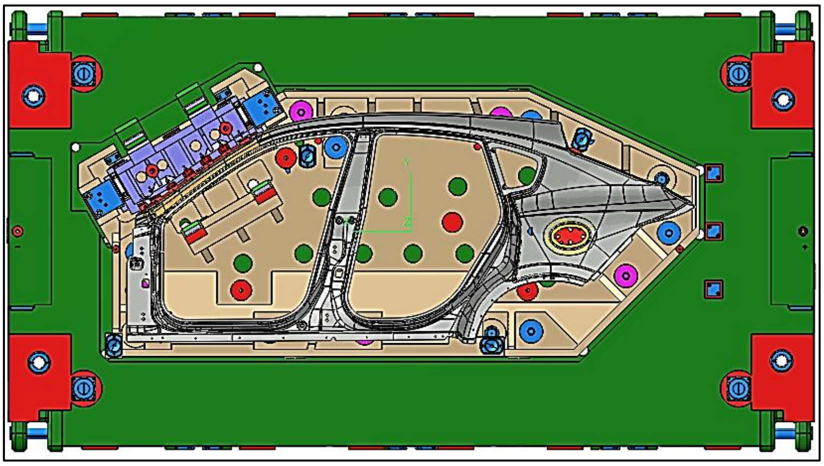


Figure: piercing die

Blanking die gives the sheet an initial 2D shape. Sheets arrive firstly wrapped in coils, which are therefore cut in pieces in the production line, according to the component's size requirements. A sheet block is therefore produced, in rectangular or trapezoidal shape, without scraps. Some body components can be directly manufactured, others instead – such as sides-, require a dedicated procedure. Proper size, are calculated from the drawn element, taking account for example flanging sides. Therefore, a utilization coefficient is calculated, evaluated and optimized to the highest amount possible. Generally, given the relatively simple shape, sheets are cut at high cadency press (18-20 strikes-per-minute).

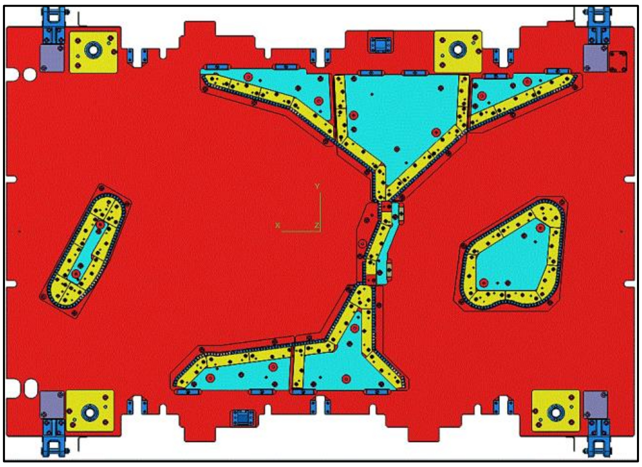


Figure: blanking die

1.4.2 Forming dies

Forming is a general term used to describe a stamped part whose shape and contour is reproduced directly from the shape and contour of a die set. The main forming operations accomplished with press mounted dies are:

Draw die drawing is the mandatory operation following OP10 Cutoff, which plastically deforms the sheet, until it reaches an appropriate 3D shape.

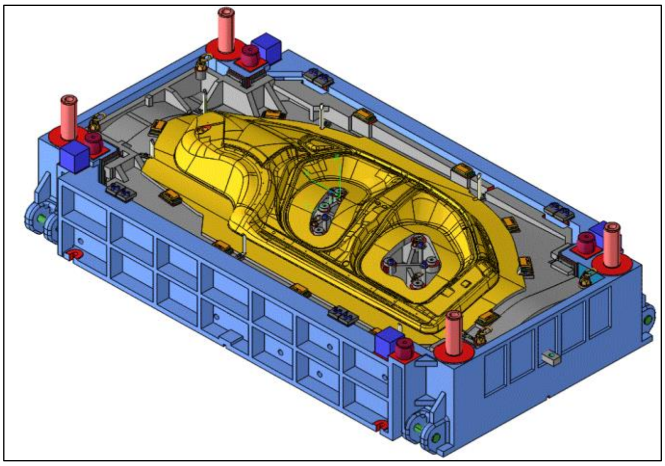


Figure: draw die

Flange die also called forming, generally follows trimming. Sheet is deformed in order to generate flanges. This applies in areas where high torsional and bending stiffness are required, such as the Front Pillar and/or the Rocker. Flanges therefore allow reinforcements, that give stiffness to the vehicle, according to the small sheet thickness. These operations are exclusively possible with CAM slides (as for the Rocker), or using a rotoCAM as implemented on the Front Pillar.

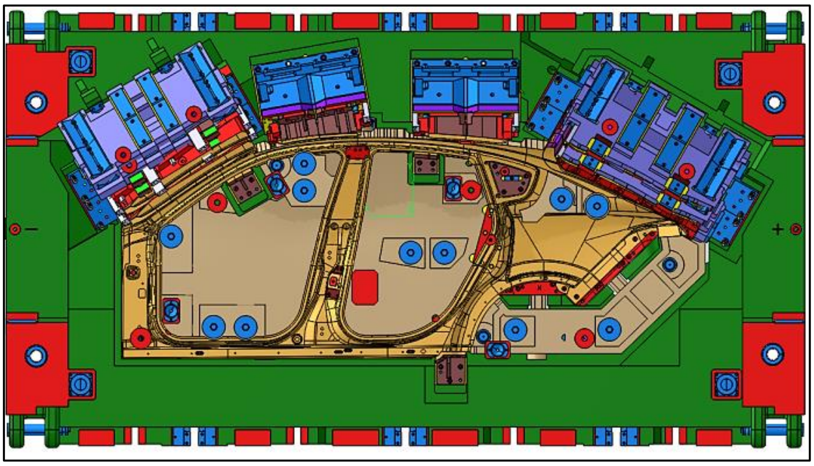


Figure: flange die

Restrike die are applied to internal and external sheet perimeters, verifying interested areas fit geometrical and tolerance requirements. This can be considered as a “calibration” operation, particularly on small radiuses, impossible to actuate on OP20. Therefore it is preferable to firstly draw (OP20) with a large radius, in order to restrike on the next operations. Also, plastic strains due to Draw Operation, generate residual stresses, therefore implying low-quality components. For this reason, a Restrike is mandatory.

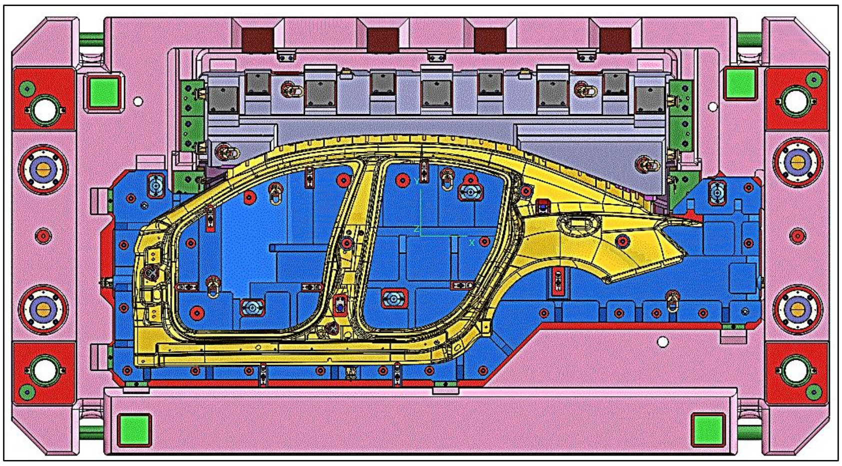


Figure: restrike die

Multiple stamping operations may be performed within a single die, or at a number of die stations within a die set and with a single stroke of the press.

In this thesis, we are focusing on the engineering and manufacturing process of automotive dies.

Chapter 2 Current workflow of die engineering and manufacturing

2.1 Overview of all activities

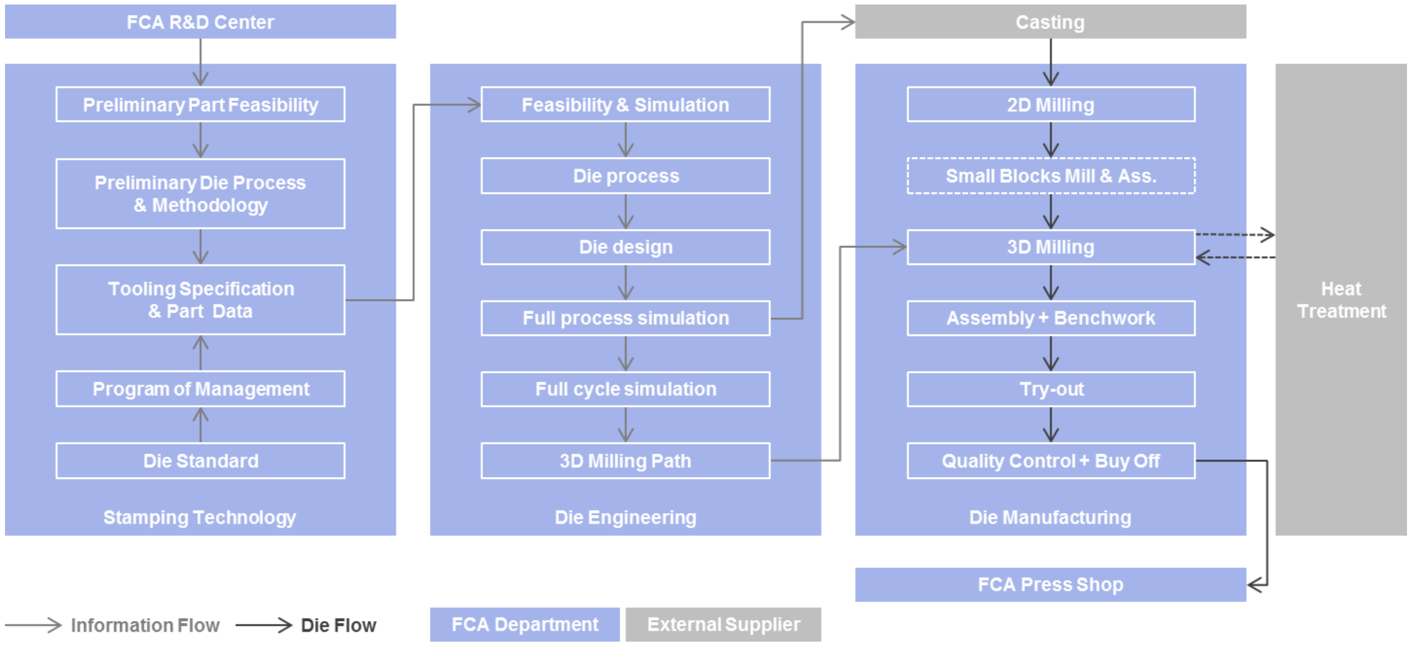


Figure: overview of the workflow

<u>Technology operations:</u>

Technological development process starts right after planning phase, that is, after decisions have been taken regarding car model, manufacturing plant and commercial launch time estimates.

At the beginning, stamping division workloads are analyzed, specifically to the manufacturing plant, in order to assign make and buy serial numbers.

Make serials would be produced inside manufacturing plant, whereas buy ones would be assigned to suppliers.

The last ones will be registered and included in the so-called Vendor List: a resume including all the suppliers involved in the process, to which a budget is assigned, fixed or variable.

Once the so called Zero Contract Document - Scheda Zero Contrattuale has been approved, technological development of a new model begins.

<u>Engineering operations:</u>

Feasibility, die process, die design, Simulation and VTO, milling path design (CAD/CAM). These operations are not in series, but often in parallel and interaction. There are many feedback loops among them.

<u>Manufacturing operations:</u>

Machining: first activity in die construction workflow. 2D and 3D milling are made on casting models (cast iron or steel). All machines use a numerical control system (CNC), in order to generate the necessary shapes inside the acceptability range. Also heat treatment should be done one some specific components at different time during machinning

Die construction progress is considered at **35%** completion after this phase.

Assembly: the following step where casting models are hand-finished to eliminate any machining surface defects. Die components are therefore assembled following the necessary procedures, specified by dedicated documentation. Systems, components and subcomponents should be also taken account of.

Die construction progress is considered at **75%** completion after this phase.

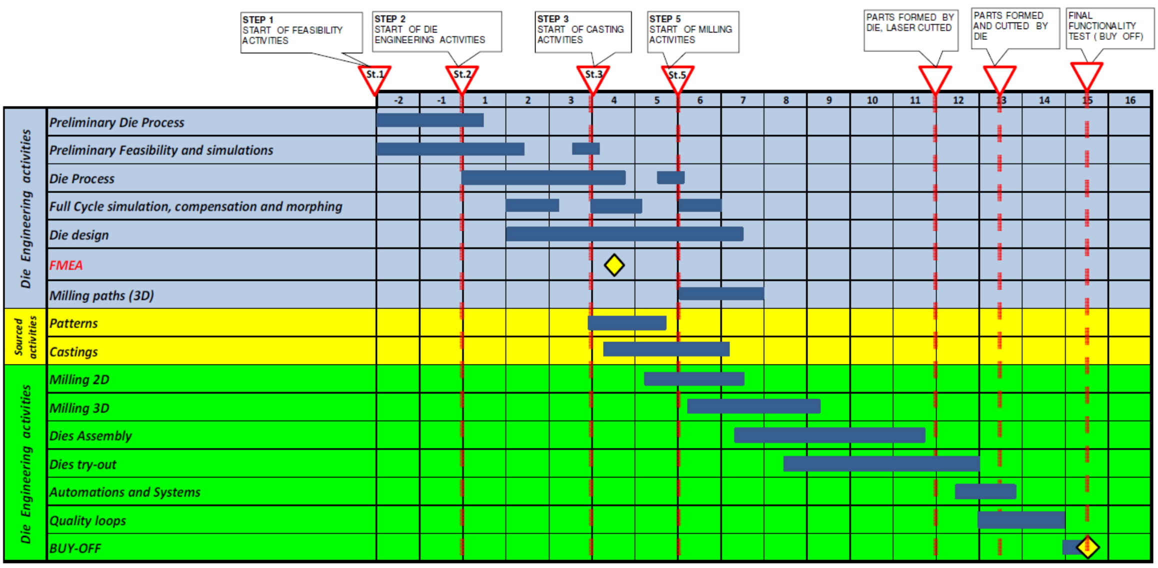
Try-out: dies are mounted on the specific spotting press. This allows to locate any non-congruencies (such as breaks, wrinkles, waving …) and correct them, using a continuous loop. All the testing performed is the so called Prima/Seconda Messa a Punto.

Buy-off: stamped components are therefore checked and measured. Implementing any further modification cycles will eliminate emerged non-conformities found in this phase.

Die construction progress is considered at **90%** completion after this phase.

Delivery and on-line installation: when all non-conformities are solved, dies are sent to the manufacturing plant, which represent the final user. A final tryout is implemented in the production line, in order to allow the components series production, which has to meet certain requested characteristics (such as quality and production frequency). Simulation of all movement and translation mechanisms is implemented.

<u>Time to market:</u>



In actual die design and construction, it's impossible to do each job mentioned above one by one. Because some activities have to be done in parallel to save time. The actual workflow is regulated by a management method called Time to Market (TTM). TTM is the length of time it takes from a product being received from R&D department until its being available for mass production. TTM is important in industries where products are outmoded quickly. A common assumption is that TTM matters most for first-of-a-kind products, but actually the leader often has the luxury of time, while the clock is clearly running for the followers. TTM is one of the key measurement of the work efficiency,

According to the TTM of FCA die shop, more or less 15 months are needed to build a die from to buy-off. And there are 7 check points:

- Step 1: technology department receive the model from R&D department, Feasibility and pre method start at the same time.
- Step 2: Engineering department receives model from technology department,
- Step 3: Foundry receives the nominal model from engineering department, start of casting and after the construction department recerves the casting 2D milling starts (nominal surface).
- Step 5: Start of 3D milling (morphed surface)
- VP: verification part by laser machine
- PS: pre-series part on production line
- Job 1: start of mass production

Technological die development involves directly Die Shop Mirafiori Plant, and it is regulated by the so-called Time To Market (TTM) scheme, which covers a time window of approximately 15 months.

This document sets the pace for all the die development necessary operations, which are themselves mainly divided as follows:

<u>Die engineering: Steps 1-5</u>

In the grand scheme of things it can be seen as a progressive refinement work, whereas at Step 1 all of the vehicle aesthetical surfaces are available (with only few of them mathematically modeled), advancing through Steps 2-3 and reaching Step 5, where all mathematical surfaces are available, enabling therefore die production "kick-off" and all its necessary machining setups.

Specifically, taking a closer look at all phases, one can see that:

- Step 1: aesthetics feasibility is evaluated, all C-class mathematical surfaces completed as much as flanging surfaces, radiuses and embossments.
- Step 2: feasibility and simulation studies begin, stamping methodologies are assigned and die design starts. Process is embedded in the stamping process development, parallel to other activities such as flanging, painting and assembly, directing involving all other vehicle development departments. Holes axes, tolerances and correlations are in this very moment defined. Eventual non-conformities, ruptures and/or sheet splits are so localized

and resolved by assigning the optimal geometry configuration and/or press operating parameters. Geometry can also be modified by introducing a so called Overdraw, which allows to remove all defects.

- Step 3: all B-class mathematical surfaces are modified to meet the appropriate standards and criteria. Reference points are fully defined. Casting models are generated, in order to receive them at the next step phase.
- Step 5: final mathematical surfaces are released, casting models are therefore received and milled inside the plant. As the Process Engineering studies advance through Step 2 and Step 3, towards Step 3 machining process is modeled.
  All procedures are here implemented in order to guide all the machining operations. Therefore, timing is now calculated and CAM (Computer Aided Machining) programs are compiled. An important remark is necessary regarding the latter, in which particular emphasis is given to machining collisions.

Die manufacturing: VP and PS

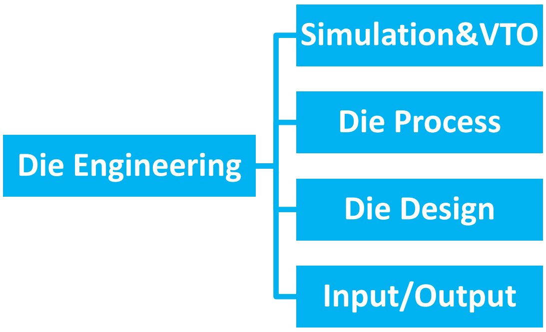
Casting models machining sets the mark for the physical die construction, which extends throughout all the production lines setup phase, Process Verifications Phase (VP) and partially through the Pre-Series Phase (PS).

Goal of these phases is to progressively reduce the gap between Jumping to final phases, one can remark that Press Shop receives the completed dies no shorter than one month before completion of the so-called JOB 1, which is the first Series Production commercialized vehicle.

Figure explains the development phases sequence in a schematic way, paired with general necessary operations.

2.2 Die engineering

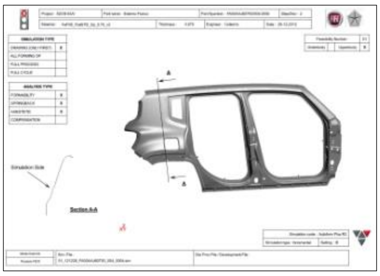
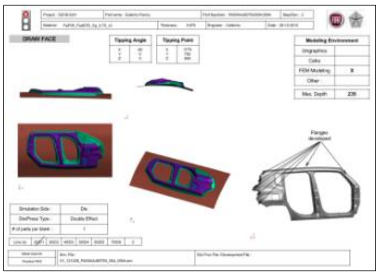
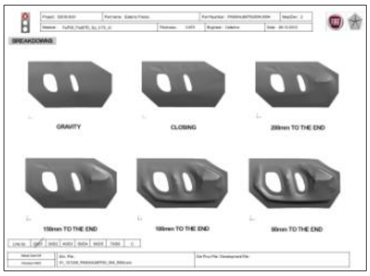
Department division



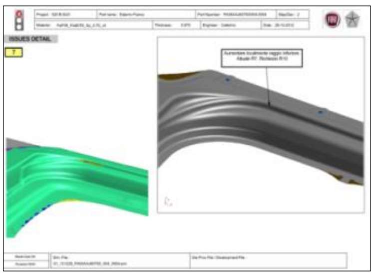
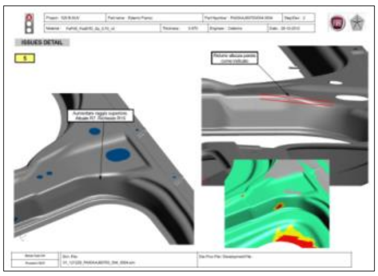
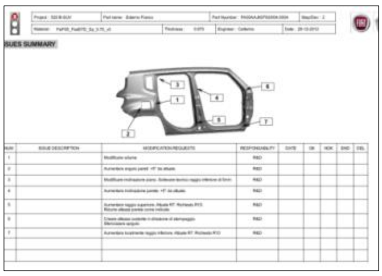
Process feasibility

The first step of die engineering is to do process feasibility. Rough simulation (mesh) in engineering area to check feasibility.

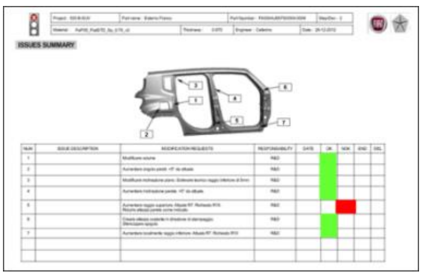
- Product feasibility by Autoform and NX.

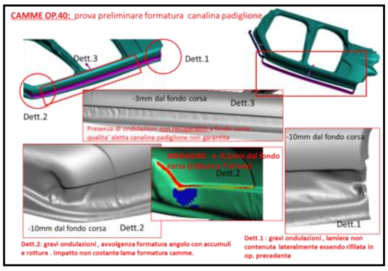
- Write the report of Issues in detail and indicate modification request.

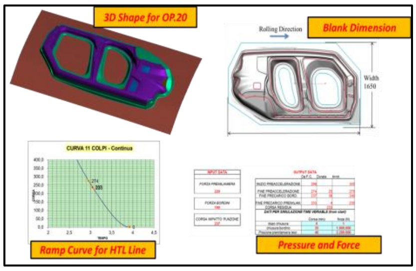




- Check model updates with modification.



- Process feasibility for all forming operations.



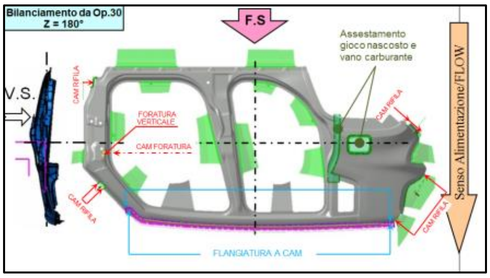


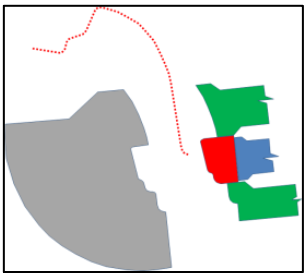
After these check and modification, all those info are now available for 3DDP, press line simulation and draw design.

<u>Die process</u>

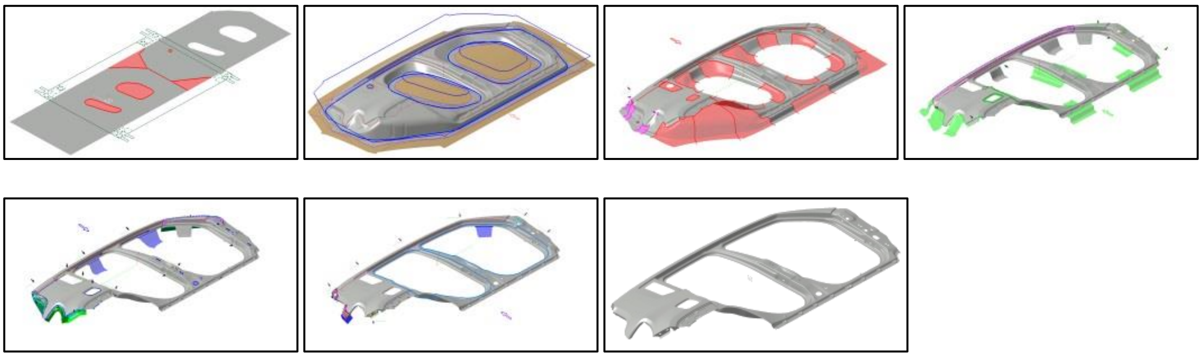
From 6-box to 3D process, surface for simulation and dies engineering.

- Receive 6-box from technology area. From 6-box to 2D Die process study.





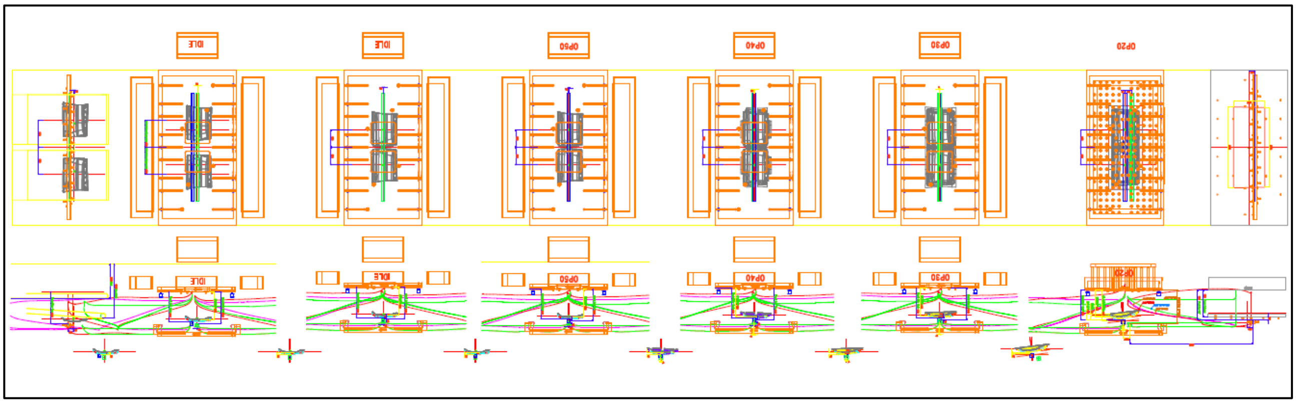
- When making the 2D process study, trimming angle should be checked (from -15 to +20).
- If need any modification, request technology area.
- During the cutting, consider about the angle and the size.
- Then 3D Die process (3DDP) for every operation.



The out put of die design is 3DDP, 2D die design study, 2D method plan, updated 6-box and Cheklist for die process.

Throughput simulation (collision with press equipment)

- Definition of type of press production line and automation
- Production cycle definition
- Dynamic simulation of production rate and elimination of possible collisions



Dies heart component collision (collisions between die components)

- Check component interference
- Check filler cam movement
- Check slide came crash
- Check all components moved

These two operations should be done after die design. So here is a loop between die process and die design.

Die Design

Die design starts after die process.

During the design phase, the necessary manufacturing methods as well as the sequence and number of production steps are established in a processing plan. In this plan, the availability of machines, the planned production volumes of the part and other boundary conditions are taken into account.

The aim is to minimize the number of dies to be used while keeping up a high level of operational reliability. The parts are greatly simplified right from their design stage by close collaboration between the Part Design and Production Departments in order to enable several forming and related blanking processes to be carried out in one forming station.

Obviously, the more operations which are integrated into a single die, the more complex the structure of the die becomes. The consequences are higher costs, a decrease in output and a lower reliability.

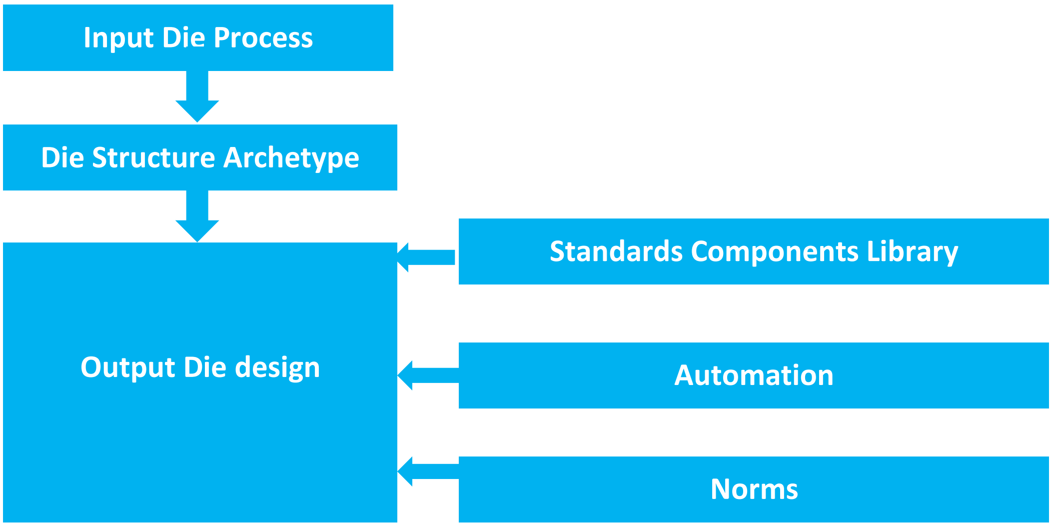
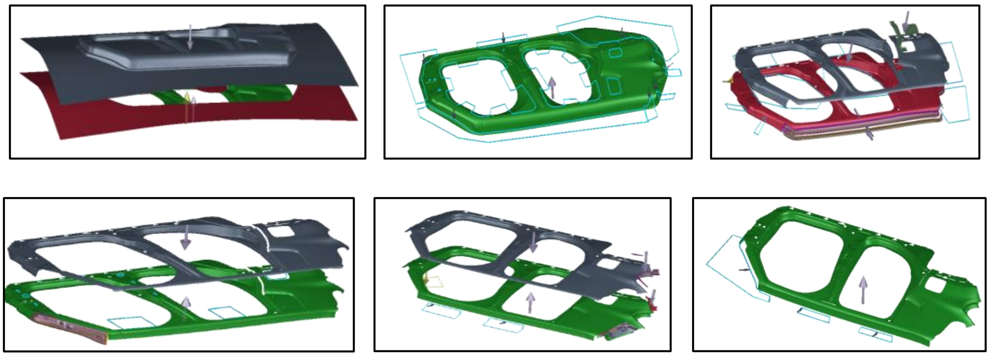


Figure: die design operations and process

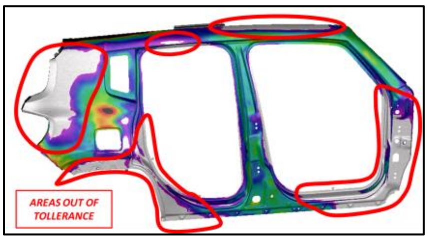
<u>Full process and full cycle simulation</u>

Full process starts at the same time with die design after die process.

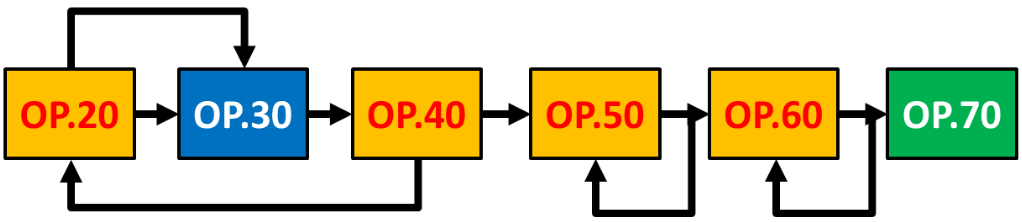
- From 3DDP all the 2D and 3D process data, simulation tools build and process setup



- During this phase Springback is checked: geometrical defect



- Compensation Strategy



After compensation. The die model will be ready for NC milling. Moreover, aesthetic issues should be also considered in this phase.

Milling path design

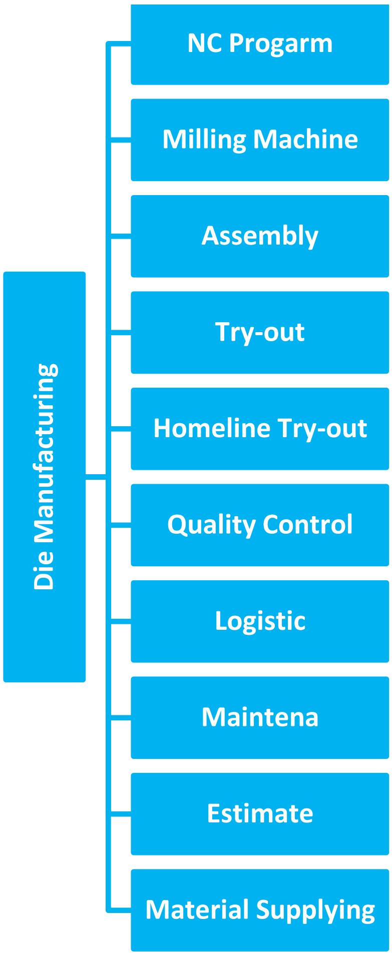
This operation transfers the die components from CAD to CAM. Main procedures are:

- CAD surface morphed from simulation
- CAD make operation surface
- CAM make file ISO usable to CN on milling machine

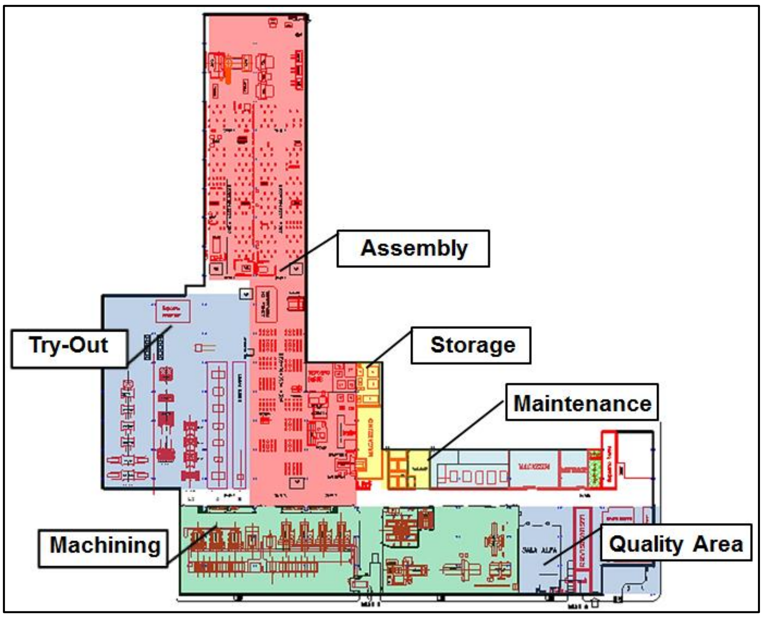
In CAM we also check the collision during surface milling, then change the milling angle and the milling path.

2.3 Die manufacturing

Structure of die manufacturing department:



Here presented are all elementary technological units-UTE of which FCA Die Shop Mirafiori is composed. Basically, one can find 6 UTEs inside the facility:



Storage is the first operative unit to which material is shipped, received or stored. Four sub-units are identifiable:

- Main Storage: here are kept items such as commercial components, nitrogen cylinders, bushings and guiding cylinders, punches and dies, wear plates, compensators, URELAST rubber plates, locating cones and so on.
- Second Storage: all surplus components, remains from previous projects, disbanded material.
- Bar Storage: bars and maintenance/cleaning material.
- Main Bar Storage: keeping all iron materials, it is located in proximity of machine tool area.

Activities:

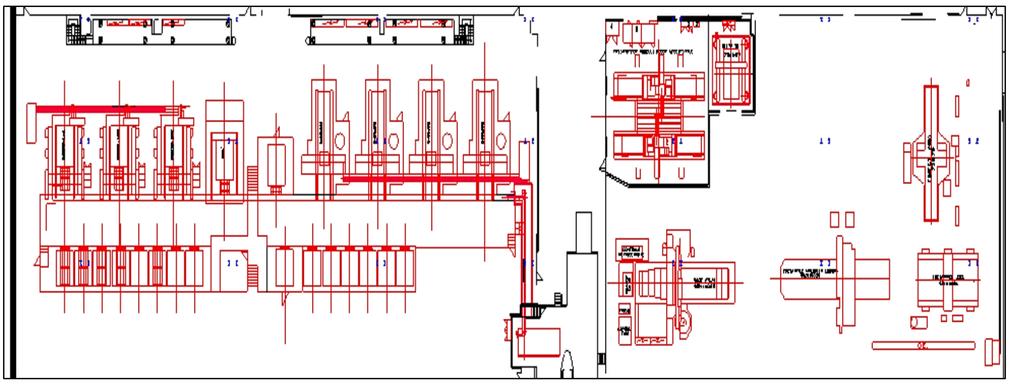
- Shipment acceptance: all necessary production material (mills, mills inserts, rivets, tools, clothing, etc.), dies commercial components, castings and heat treated components in outsourcing.
- Material shipment: machined components which require eventually a heat treatment , or completed dies destined to different facilities than Mirafiori.
- Storing: regarding assembly, herein all commercial components such as bushings, cams, locating cones, hydraulic and electric components are stored. This way, the proper UTE will receive the proper components as soon as they are needed.

Maintenance is a small unit engaged in maintenance and machine-systems repairing. Given the small size, when serious failures occur, operations are subcontracted to external maintenance companies. As all machines generally have a very complex architecture, it becomes necessary to use other maintenance companies know-hows.

2.3.1 Machining

Lay-out of machining area:

Composed by aligned machines, dedicated to various machining to be made on die components.



<u>Machining equipment:</u>

Large Machines (GRA): includes big milling machines. These two machines only do 2D milling for service planes with 2 worker/shift. These 2 machines are respectively:

- Machining Center Waldrich Coburg
- NC Vertical Milling Innse Atlas

Figure: Waldrich Coburg Figure: INNSE Atlas

Medium Machines (MMU): inclusive of horizontal axis milling machines.
They can be considered smaller when referred to the previous area ones: these machines are dedicated to smaller components than die ones (such as bases, punches, blankholders, etc.). Four milling machines are here to be found:

- Machining Center Waldrich Siegen Ingersoll
- Horizontal Milling and Drilling Machine Ceruti
- MECOF 3 + 1 Axis Machining Center
- NC Vertical Milling Rambaudi 2000

Figure: Waldrich Siegen-Ingersoll MC Figure: Ceruti Drilling Machine

Figure: MECOF Machining Center Figure: Rambaudi Vertical Milling

Flexible Manufacturing System (FMS): an advanced machining line, divided in 3 parts:

Figure: Flexible Manufacturing System

- Rough milling (SGR): consisting of 4 “NC Machining Center Rambaudi - 5 axis” milling machines. 3 machine heads are typically used: a 3-axis , a 90° dedicated to vertical surfaces and 5-axis one. These machines do secondary milling and service planes 2D/3D, Pre-finishing 3D milling with 4 workers/shifts.

Figure: Rambaudi Rough Milling Machines

- Finishing (FIN): carrying on in the FMS, 4 finishing machines are found. 3 of them are “NC Machining Center Forest – 5 axis” while the other one is “Machining Center Parpas – 5 axis”, especially dedicated to superfinishing. These machines do 3D high speed milling with 2 workers/shifts.

Figure: Parpas Finishing Machine

- In the middle of the FMS line there’s also a post-machining “3D Measuring Machine DEA Delta SP”. Its task is to check geometrical -*but not dimensional*- tolerances. Common checks between reference planes are planarity, orthogonality and parallelism.

As a particular feature, loading and unloading between workstations is done through a electro mechanical system. That is, using a shuttle rail allowing the pallet movement. A dedicated User Interface is also necessary, allowing to command, check and control all manufacturing operations. Moreover, a special cleaning and maintenance station is present on the line.

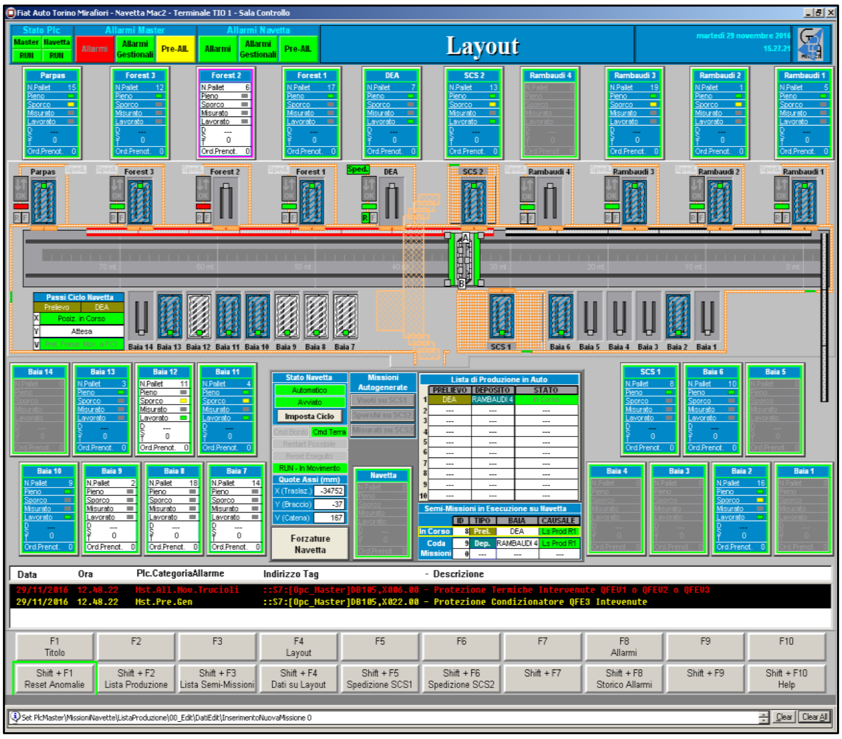


Figure: FMS User Interface

Milling operations:

Depending on the number and type of machines used, a different machining operation has to implemented. Specifically, these are:

- Reference plane milling: this is the first machining performed on the rough casting, previously received from the suppliers. GRA macro-area takes account of the operation.
- Flash surface machining: mandatory after die is thermally treated. Because of induction-TTs, one can find strains on the casting profile, as common as for punches. For this reason, this re-machining has to be implemented in GRA macro-area.
- Keller-Contours Rough Milling: allows to remove the initial 7mm allowance on the rough casting. RAMBAUDI machines on the SGR line fulfill the task.
- Blades machining: after scribing and assembly on the casting, blades have to be reworked on the RAMBAUDI machine.
- Pre-Finishing: represents the first operation on the component (i.e. punch, blank holder). Typically (FIN) FOREST machine take account of the operations (FIN-area).
- Super-Finishing: it is the last operation, which allows to erase all the remaining allowances. Typically, FOREST 3 or PARPAS machines (FIN-area) are able to fulfill the task.

Heat treatment:

Some die components require a heat treatment in order to hardening its surface during the machining process. The timing are different depending on the type of the parts. The heat treatment is not done in FCA die shop but by external suppliers. The table following shows the parts and timing to heat treatment:

Hardening Execution Timming	
Heat Treatment Tipology and Application Strategy	
Description Die	**Machining Activities**
Draw	
Punch	SGR PREFIN FIN TT2
Cavity (only binder ring zone)	SGR PREFIN TT1 FIN
Cavity	SGR PREFIN FIN TT2
Binder Ring	SGR PREFIN TT1 FIN
Trim (contouring)	
Punch	SGR PREFIN TT1 FIN
Upper Steels	SGR PREFIN FIN TT1 or TT3
Scrap Cutters	SGR PREFIN FIN TT1 or TT3
Restrike and Flange (contouring)	
Punch	SGR PREFIN FIN TT2
Upper Steels	SGR PREFIN TT1 or TT3 FIN
Blank (contouring)	
Upper Steels	SGR PREFIN TT1 or TT3 FIN
Lower Steels	SGR PREFIN TT1 or TT3 FIN
Introduction to Complete	
Symbol	Heat Treatment
TT1	Induction Treatment
TT2	Laser Treatment
TT3	Furnace Hardening
TT4	PVD/DLC
TT5	Chroming (HTTP)
Symbol	Machining Activities
SGR	Rough Milling
PREFIN	Pre-finishing
FIN	Finishing

2.3.2 Assembly

Assembly area are divided in two macro-areas, each having different subunits and machines, including:

Small Machines, which are dedicated to small components machining. Some of these are lathes and EDM machines, necessary to produce components derived from metal bars, such as risers and so on.

Spotting Area, where die components are welded, in case defects are found. Also induction heat treatment is here performed, applied to blade or punch radiuses.

- Scribing in UTE 51.02: blades are here prepared for incoming FMS-machining.
- Press Spotting in UTE 51.02: verifies correct components coupling , specifically between upper and lower bases by mechanically closing the die without applying power.

Last two types belong to one UTE, however they are used also by Try-out UTE.

Further activities include:

- **Manual surface polishing: typically follows machining, allows to reduce surface roughness. Typical components subjected to manual finishing are blank holders and its draw beads, punches and draw dies.**
- Components assembly: starts with cylinders and bushings mounting, therefore moving onto wear plates, which guide die descent. Piercing dies and punches are therefore assembled, nitrogen cylinders and inserts regulating blank holders movement, connecting rods, air cylinders imposing flanging cams movement, cleats imposing horizontal movements and safety pins. Finally, blade machining are here performed.
- Trimming profiles modifications: in case tolerance requirements are not met, thus provoking die and punch position mismatching.
- Plugging/Spotting: this verifies not only proper cutting profiles, but also appropriate trimming/restriking clearances by subjecting die to a dedicated press.
- Rough castings piercing: this allows screws and/or rivets mounting, which would fix all commercial components, other than blades and reference pins.

Figure: assembly area

Figure: spotting press

2.3.3 Try-out

Partially complete dies arrive from assembly area. Try-out area is inclusive of basically two subunits:

First Try-out (PMP): it is comprehensive of 21 presses used for testing, generally use the same sheets for production components. All presses are mechanic except two hydraulic ones, highly versatile with many editable parameters such as operational oil pressure, rate of descent and so on. This customizable system would therefore simulate any process characteristic variabilities that are specific of a certain manufacturing plant. Further tests are also necessary to implement on all mechanical presses. PMP complex is comprehensive of 5 lines:

- Line A: 1 Clearing press 1000t (D.E.) + 1 Innocenti press 450t. (S.E.) + 4 Clearing 900t presses + 1 Clearing press 1500t
- Line B: 1 Danly press 950t + 1 SMG press 2000t
- Line 1: 1 Danly press 1500t. (D.E.) + 3 Clearing presses 900t. (S.E.)
- Line 2: 1 Muller press 2000t. + 1 M.W. press 2500t
- Line 4: 1 press M.W 1500t. (D.E.) + 4 presses M.W 900t. (S.E.) + 1 press M.W 2500t. (D.E.)

Try-out tests often lead to further die modification requests. Moreover, broken and/or overstrained sheets are refused. Acceptable, non-broken elements, are however checked for eventual tolerance non-congruencies by Quality UTE.

Die final assembly: last operations are here performed. Furthermore electrical and bleed systems are installed, scrap chutes and rollers. Finally, die is painted and marked accordingly to actual standards.

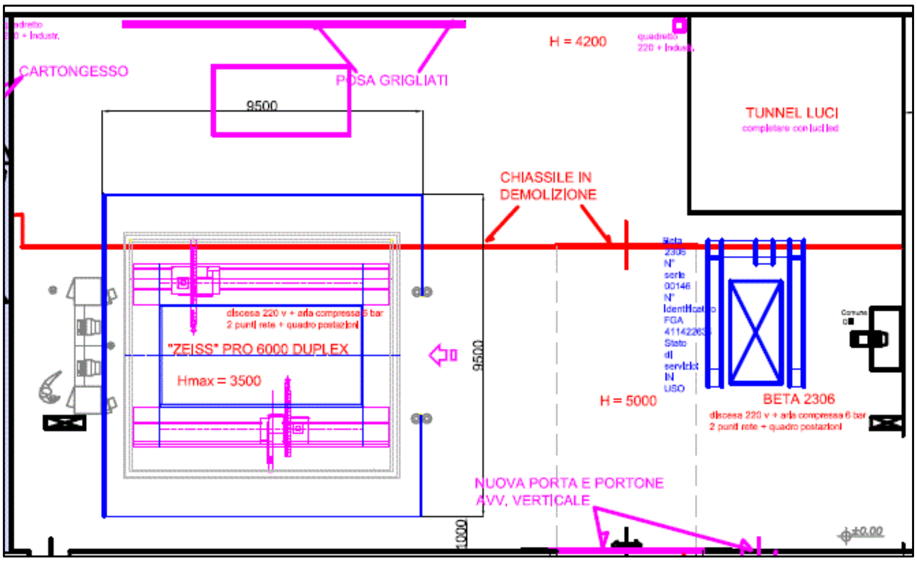
Figure: try-out Press Lines

Figure: systems installation area

Once all system are being installed, a series of performance tests is mandatory, according to norm requirements. Typically, all bleed-electrical systems undergo a bench test cycle.

2.3.4 Quality control

Lay-out of quality area:



All stamped sheets and die components are here checked, focusing more on the first elements. Two workstations are here found:

Metrology Room: all stamped sheets are here dimensionally checked. Horizontal and vertical machines are here used (the last would emulate operating position on the vehicle, for body sides, doors, and so on.) to detect and measured verification point. Metrological Analysis Machines here used are:

- Zeiss Pro 600 Duplex
- Retrofitted DEA-Beta 2306

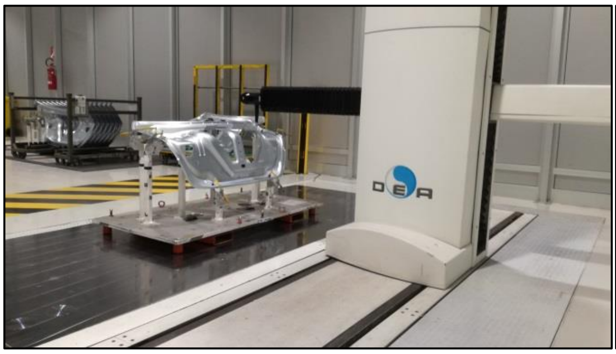


Figure: DEA-Beta 2306

Figure: Zeiss Pro600 Duplex

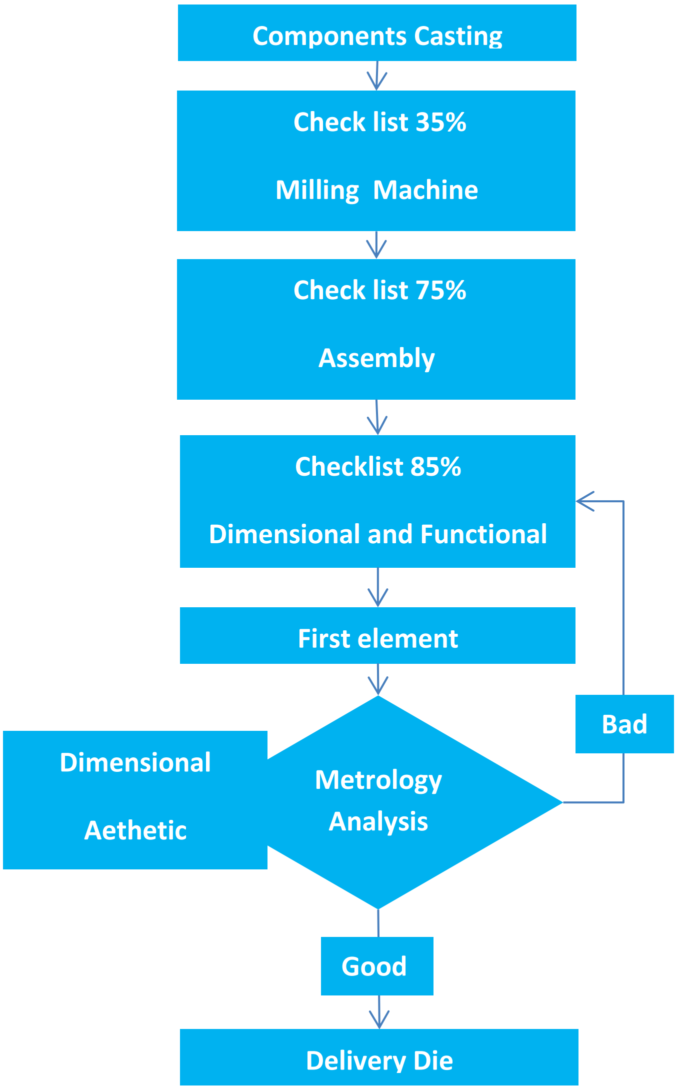
Revision area : stamped sheets with little surface defects arrive here, in order to be revised and sent to the flanging plant. A laser cutting machine is here present “Prime Industrie OPTIMO”, where trimming operations are here simulated: this shortens the tryout phase, in case the die assembly is still incomplete.

Quality checks are also implemented on rough castings; a precise schedule is dedicated to these elements. Some checks are performed by metrology staff, other ones are autonomously by working personnel, with auto-certification.

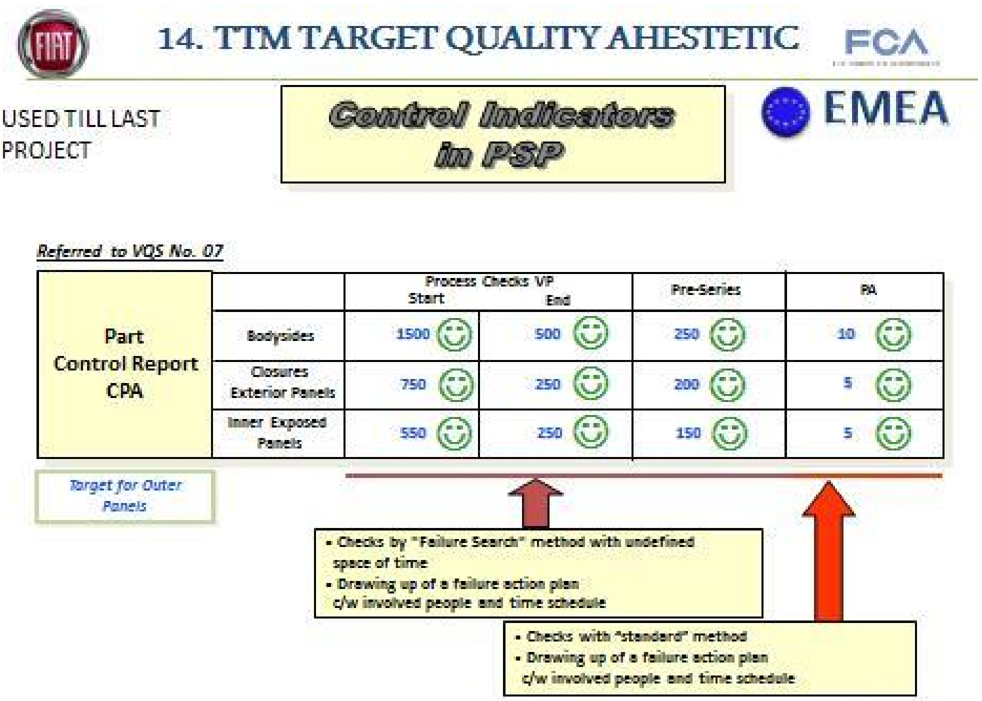
Other quality check activities:

- Check flatness before and after heat treatment
- Check hardness heat treatment
- Check hardness casting
- Check lubrication
- Check material

Quality control list and metrology analysis loop:



Quality control target focuses on both aesthetics and geometrics:


14. TTM TARGET QUALITY AHESTETIC

USED TILL LAST PROJECT

Control Indicators in PSP

EMEA

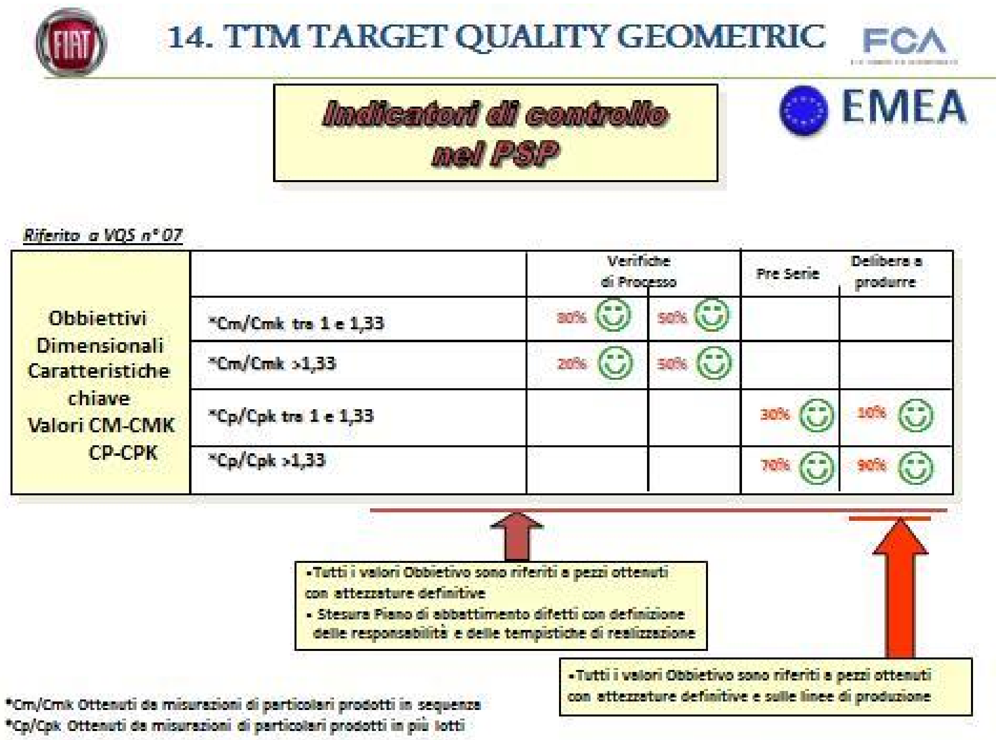
Referred to VQS No. 07

Part Control Report CPA		Process Checks VP Start	Process Checks VP End	Pre-Series	PA
	Bodysides	1500	500	250	10
	Closures Exterior Panels	750	250	200	5
	Inner Exposed Panels	550	250	150	5

Target for Outer Panels

- Checks by "Failure Search" method with undefined space of time
- Drawing up of a failure action plan c/w involved people and time schedule

- Checks with "standard" method
- Drawing up of a failure action plan c/w involved people and time schedule


14. TTM TARGET QUALITY GEOMETRIC

Indicatori di controllo nel PSP

EMEA

Riferito a VQS n° 07

Obbiettivi Dimensionali Caratteristiche chiave Valori CM-CMK CP-CPK		Verifiche di Processo		Pre Serie	Delibera a produrre
	*Cm/Cmk tra 1 e 1,33	80%	50%		
	*Cm/Cmk >1,33	20%	50%		
	*Cp/Cpk tra 1 e 1,33			30%	10%
	*Cp/Cpk >1,33			70%	90%

- Tutti i valori Obbietivo sono riferiti a pezzi ottenuti con attezzature definitive
- Stesura Piano di abbattimento difetti con definizione delle responsabilità e delle tempistiche di realizzazione

- Tutti i valori Obbietivo sono riferiti a pezzi ottenuti con attezzature definitive e sulle linee di produzione

*Cm/Cmk Ottenuti da misurazioni di particolari prodotti in sequenza
*Cp/Cpk Ottenuti da misurazioni di particolari prodotti in più lotti

Chapter 3 Weak point in current workflow and potential solutions

3.1 Weak point identification and description

3.1.1 Die surface roughness requirements

For trimming dies and forming dies, we have surface roughness requirements after finishing, in order to:

- Have a robust and repeatable manufacturing process.
- Lengthen durability and efficiency of surface treatments which are particularly sensitive to surface roughness.
- Fulfill aesthetical requirements regarding "Premium Brand" vehicles with Aluminum body components.

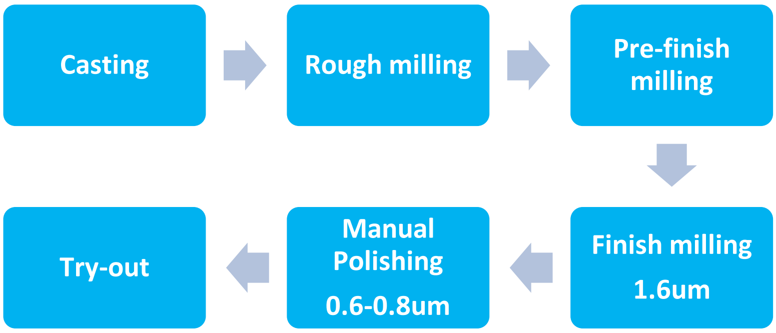
Following table and notes show the roughness requirements for finishing the working surface of forming die and trim die components:

WORKING SURFACE	ROUGHNESS REQUIREMENT [Ra]
Post-Punch-Cavity	0.3-0.5
Cam Slide-Fill Cam	0.3-0.5
Binder Ring-Pad	0.3-0.5
Trim Steel-Insert	0.3
Flange Steel-Insert	0.3

- Flange and trim steels that require PVD coating, require a surface roughness of Ra=0.2.
- The finishing must be very accurate. Small defects generate dust or slivers in the die.
- The trim steel finishing has to be done in trimming direction.

3.1.2 Current method and results

Our current manufacturing process of forming dies requires several automated machining activities (rough milling, pre-finishing, finishing) and a manual activity (polishing):



Figures above visually show the surface roughness changes of a punch during the manufacturing in our die shop. They are casting from foundry, punch after finish milling and punch after polishing. From the first one to the second one, fully automated CNC milling is used. Form the second one to the third one, manual activity is performed. And after polishing, the surface roughness requirement mentioned above should be achieved strictly.

But now, the roughness after manual polishing cannot always meet the requirements perfectly (0.6um-0.8um) and the working time is highly depend on worker's experience which leads to an unpredictable TTM.

So, we have to indicate that manual polishing of forming dies and trim dies is the weak point in our current construction flow. It is reasonably, because it is:

- Not good result: manual polished dies correspond only 30% to the FEM model and the roughness is not always satisfying the requirements perfectly.
- Time consuming: finishing the surface by hand with stones and sandpaper costs a lot of time.
- Low predictability of TTM: working time highly depend on the employee performance which is not stable all the time.
- Low reliability: the result in dependent on personal experience and the craftsmanship of the employee.

Figure: Forming die (cavity) manual polishing

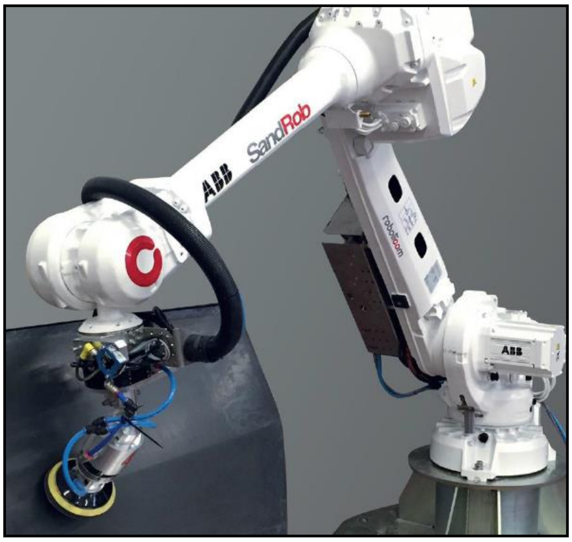
3.2 Innovative technologies alternative in the market

For the aluminum stamping it is very important to improve the die roughness in order to limit the typical defects created by rubbing and dust flaking, deriving from the characteristics of aluminum during the forming and trimming phases. Failure to adjust the die roughness to work with aluminum causes production stops due to maintenance and cleaning of the die and machinery.

We have researched suitable technologies to improve the die roughness with repeatable results, also using automatic processing with reduction of hours. The technologies on which we are studying are the following:

- Surface polishing by robotic sanding (SandRob system)
- Surface micro-forging called hammer peening by compressed air (SemaTek system)
- Surface micro-forging called hammer peening by electromagnetic (Accurapuls system)

3.2.1 Surface polishing by SandRob system

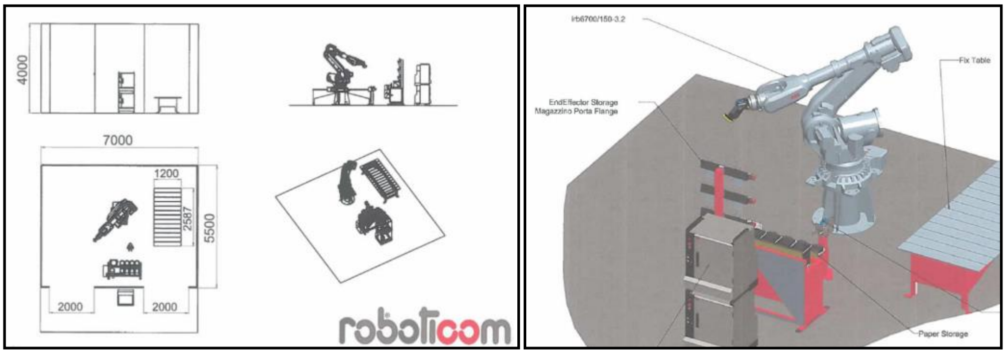


<u>Working principle:</u>

Use of abrasive discs mounted on a rotating head driven by a 6-axis CNC industrial robot, which follows the path generated by the numerical model of the element to be polished. The discs can have varying roughness degrees to achieve the desired finish level. It is necessary to use a specific software that can dialogue with CAD and CAM.

In addition to sanding operations, the work group can be also used for drilling, milling and cutting with waterjet, by changing the head which can be automated.

Hypothesized lay-out:



Current applications:

The supplier has no specific experience in polishing steel elements. During the visit to the their headquarters we have seen elements polished in aluminum and one in carbon fiber. The level of polishing of these elements does not fully meet our polishing needs molds.

Feasibility to automotive die polishing:

There is no previous application on automotive dies which have much more complex suface. The technology supplier need to do feasibility on automotive dies.

Surfaces in red can be polished with the end effector we have available, after appropriate adjustments concerning the tools to be used and the process parameters.

Surmountable surfaces that in the case of the external door punch above are prudentially in the order of 75% -80% while for the side framework we estimate around only 60%.

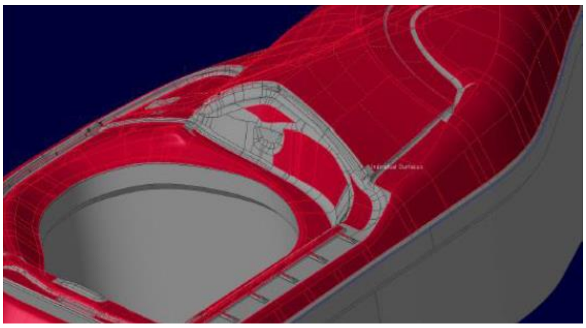


Figure: feasibility exemplification on a draw die surface

3.2.2 Surface polishing by SemaTek system

Sematek takes care of the complete supply of the polishing line, including the robot. The hammering tool head is produced by 3S Engineering and called FORGEfix. It can be mounted either on a robot or on a CNC machine. This polishing system is used in BMW MECANER. The goal is to reduce the manual sanding phase completely or to eliminate the whole. According to data from Daimler, which has been collaborating with Sematek since 2011 to develop the system, manual polishing times are reduced by about 60%, from a rate of 50 h/m2 to 20 h/m2. SemaTek currently provides all German and some foreign manufacturers, including the PSA group.

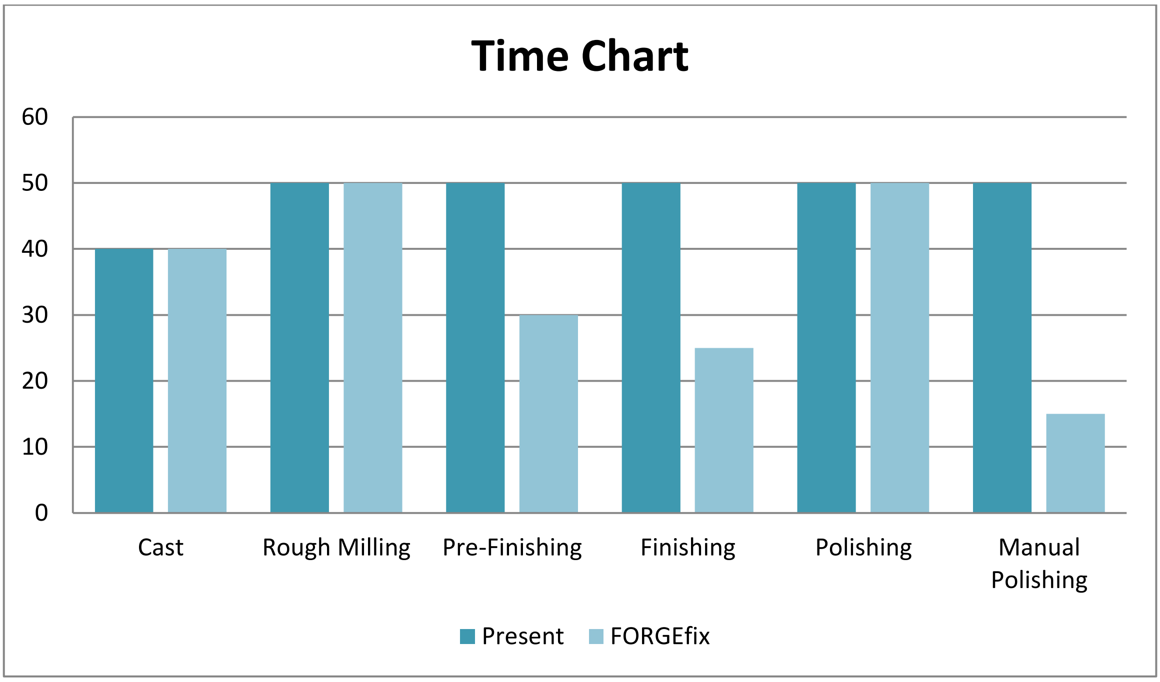
<u>Working principle:</u>

The surfaces polishing is obtained by means of indirect high frequency micro-forging (about 220 strokes/second) which is impressed by a mobile device inside the tool on the working head, in order to avoid backlashes to the drive unit (CNC milling machine or robot). The principle is based on the abatement of machining crests left by CNC milling machines and on surface compaction. Surface hardness is also slightly increased (GG25: +30% approx., 1.2379 hardened: +3.5% approx.). The operation can be performed depending on the needs, both on steel in the natural state and tempered.
The tool works with compressed air supply and does not need rotation during movement.
Hereafter the data on the roughness achievable and on the increase of the hardness of the various materials after processing, according to the data of the supplier.

Results in surface roughness for different materials:

Material		Status	Result			
Standard	Tensile Stregth		Surface Roughness		Hardness	
Name	N/mm2		Ra [µm]	X Times	HRC/HRB	%
GG25	300	Before	1.700	**5.00**	167.0	**31.70%**
		After	0.340		220.0	
Al 3.7075	500	Before	1.500	**12.82**	61.2	**5.23%**
		After	0.117		64.4	
St 52	500	Before	2.700	**12.22**		
		After	0.221			
1.2312	1000	Before	1.461	**20.29**	31.2	**5.77%**
		After	0.072		33.0	
Toolox 44	1400	Before	0.497	**4.36**	43.7	**5.46%**
		After	0.114		46.1	
1.2379 hardened	2100	Before	0.100	**2.08**	58.2	**3.61%**
		After	0.048		60.3	

Results in time saving for different machining activities:

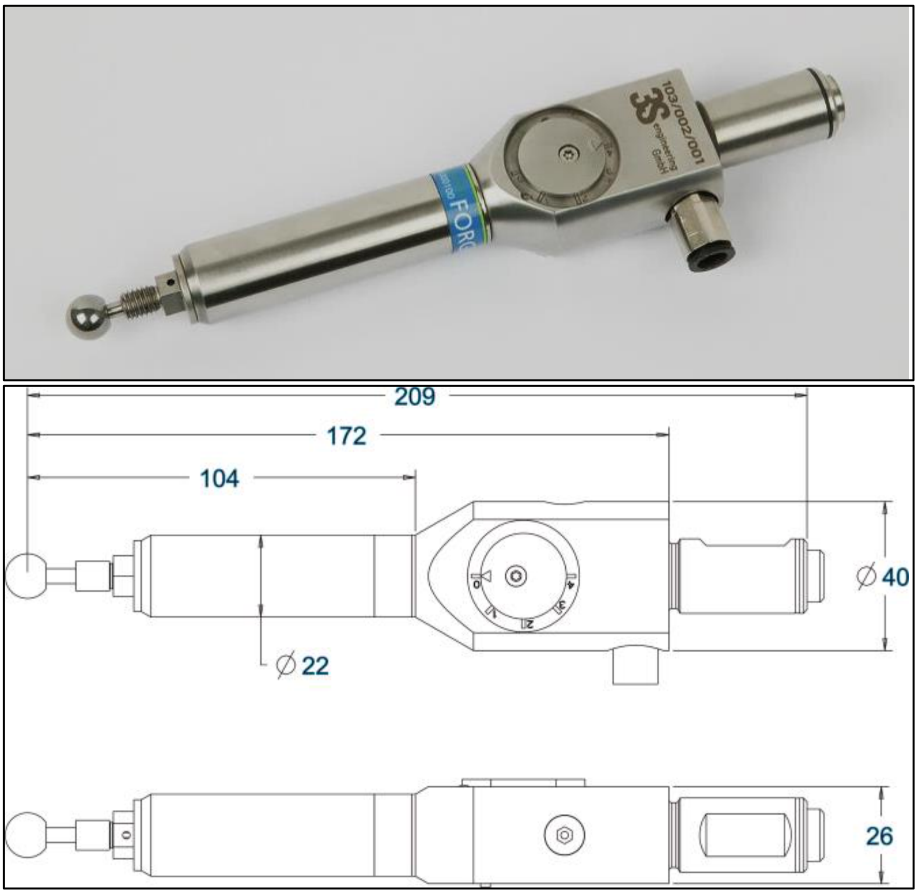


Technical features of the tool:

PNEUMATICALLY OPERATED TOOL WITH A OSCILLATING HAMMER HEAD FOR MECHANICAL SURFACE TREATMENT (MHP) OF FUNCTIONAL SURFACES.

- Total length: 209 mm
- Holding fixture: Weldon Ø 20 mm
- Frequency: approx. 250 Hz

- Force contribution: ca. 500 N (SP-Setup)
- Head diameter: 3 bis 20 mm
- Stroke adjustment: 0 – 4 mm
- Air supply: 4 - 8 bar
- Type: linear/angled (60°)



Improvement for surface polishing:

- Surface roughness Ra is optimized by 2 to 20 times (Ra < 0,05µm)
- Homogeneous surface quality
- Reproducible surface quality
- No allowance is needed, because µ-deformation
- Tendential larger head diameter

Current applications:

Figure: BMW MECANER

Figure: Robotized application

There are two kinds of possible installations, Robot +HP and Milling machine +HP. Companies using this tool prefer use a robotic arm because high working frequency of the tool may cause damage to milling machine.

Cost evaluation:

In order to obtain the best results in terms of roughness it is necessary to use cast iron castings with particular compactness characteristics, which require specific expedients in the casting process. The lead time for this type of material goes from 4 to 6 weeks and the cost increases by about 8 - 9 € per square decimeter.

The hammering head has an indicative cost of 10 K €; SemaTek customers prefer to equip an area to run the business with a robot to avoid damaging the milling machine, an equipped cell could be around 150K € to 250K € (depending on the level of automation). You need to execute a specific toolpath from the CAM files used for milling.

Cost of practical test:

First phase for the preparation of 12 50x50 mm specimens prepared appropriately (material supplied by Massifond and machining at Ns load). The hammering phase would be performed in FCA with a cost of € 1,000 per day for at least 2 days, or the test could be performed at home SemaTek with a reduced cost to 1 day (€ 1000) after shipping samples.

Second step, carry out the activity on a particular (in cast iron treated) that will follow the production flow or on a test mold, to define time and cost modalities.

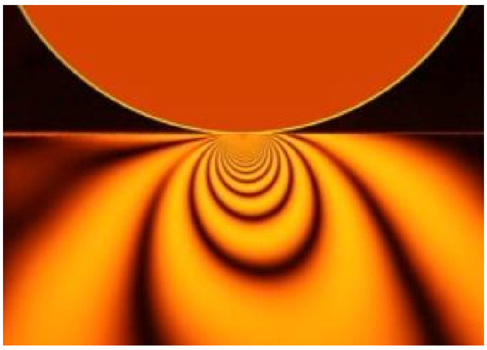
The hammering ball must be replaced every 1000 hours. The machine works at an average speed of 20h / m^2 and it is declared that the brickwork time can be reduced to 60%. The use is indicated for aesthetic details but also for frames.

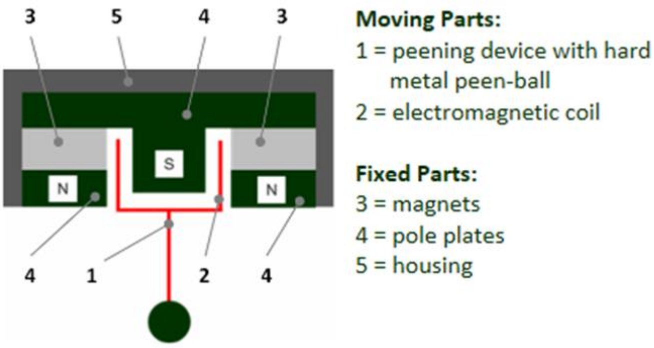
3.2.3 Surface polishing by Accurapuls system

Working principle:

The process of Accurapuls micro-cold-forging system is based on the mechanism of moving a coil electromagnetically. Due to the current flow the moving coil creates a force (Lorenz Force), which acts in direction of the coil.

This force in proportional to the induced current and it’s effective direction follows the current flow direction. Mechanical vibration can be generated through electromagnetic oscillation, by using an AC power system.





<u>Range of Application</u>

Surface refinement:

- Surface polishing
- Define surface charge
- Insert of alloying or refining components
- Reduction of friction wear in joint of construction



Hardening:

- Surface abrasion protection
- Defined surface-frictional resistance
- Increase cavitation resistance



Inherent compressive stress:

- Compressive stress implementation
- Increased thermal stability
- Reduction or prevention of crack-building
- Deceleration or prevention of crack growth
- Increased fatigue strength



Feasibility to automotive dies:

This is a quasi-mature technology for automotive die's polishing.

OEMs:

- 5 installation BMW group
- 1 installation Opel automotive GmbH Russelsheim/PSA group
- 1 installation Ford
- 1 installation Tesla

OEM tier one supplier:

- 2 installation in Germany

Other information about Accurapuls:

The roughness obtainable from this system is 0.4umm.

Accurapuls system need a specific software to make this equipment work, the variables are the frequency, the force, the stroke, the advancement, the diameter of the sphere (example working frequency 200 pulsations to the second working step 0.2mm) as the materials change from work vary the different parameters, a training course for programmers is planned.

Accurafin is the recommended practice for molds to reduce wear, surface cleaning, fillet inserts ...

Recommended process: after the pre-finishing pass, performed with 0.5mm pitch, instead of our 0.2mm laser hardening is applied and then the surface finishes with HP.

Type of molds on which HP is applied: on all external and internal parts, the recommendation is to start with parts of the backbone, to check the results and also to verify correspondence with the simulation.

BMW applies this technology frequently on loose and pre-assembled fluting / trimming blades.

Cost evaluation:

Supply of a package that includes:

- Teste2 hammering heads
- Amplificatore
- Hardware commensurate with the activity (IT must verify its compatibility with our systems)
- Software with license for one year Total cost 200 K € Software license: years following the first one, 10 K € / year.
- Training course for the use of the software (2-3 days required): 1,500 € / day Application course on the machine (according to need): 1.000 € / day

- Maintenance cycle every 500 hours of use, to be done at Accurapuls: 1.500 / € 2,000 Warranty (free maintenance): 2,000 hours (4 revisions). It is also necessary to provide an extra cost for adaptation modifications on the machines: the head loaded on the spindle bearings, can be mounted on an electrospindle only if it is properly sized.

Comparison between these three technologies:

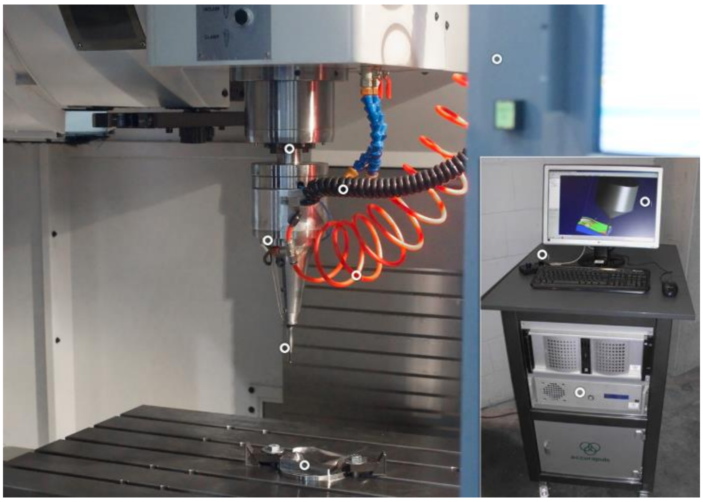
Technology	Roughness Level	Feasibility to Dies	Application in Other OEMs	Cost Evaluation
SandRob (Robot + Abrasive Disc)				
SemaTeK (Robot / CNC Machine + Hammer Peening Driven by Air)				
Accurapuls (CNC Machine + Hammer Peening Driven by Electromagnetic)				

According to the study on three different innovation technologies in current market and the comparison among them, obviously, we should select Accurapuls MCF system as a possible investment plan to improve our die roughness and shorten the polishing time.

In the next chapter we will see more detail research on Accurapuls MCF system and the test, feasibility analysis and validation for this new technology.

Chapter 4 Further study on the selected technology

4.1 Components of Accurapuls system



Peening Hammer

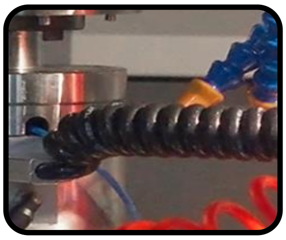
This is the Head that performs the mechanical peening operation. It is electromagnetically controlled and air-cooled. It produces the Lorenz force that causes the striker to reciprocate and make contact with the workpiece surface. Working stroke generally ranges from 0.2 to 1.0 mm. Frequency rate can range from 20-500 hits per second. Impact force is up to 180 kgs per hit, variable from 0-100%.

Striker

Interchangeable shank with integrated spherical hardened and coated steel tip. These come in a range of sizes from 1mm to 25mm diameter. Custom striker forms can be produced. For most applications strikers last a very long time.

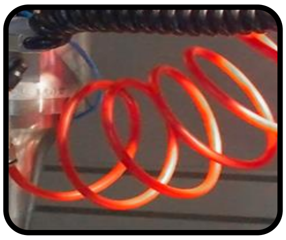
Spindle Adapter

This interchangeable flanged adapter or customized fixture secures the peening hammer to the machine tool spindle or housing.



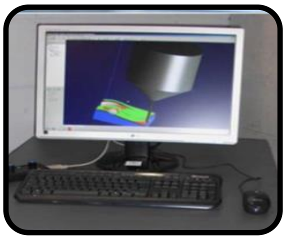
Flex Cable

Electrical cord that provides DC power from the electronics power supply unit to the peening hammer.



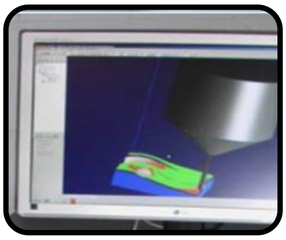
Air Hose

Supplies compressed air for cooling the hammer body.



Computer

High performance multi-processor CPU necessary to drive the Accurapuls ThorCam Software.



ThorCam Software

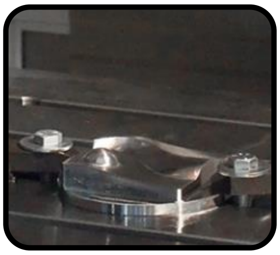
Proprietary CAM software required to control the CNC machine for peening operations on 3D geometries. Capable of up to 7-axis programs, code is generated from parasolid files for the workpiece. Unique features such as sharp edges or pin holes in the surface are recognized by the software and preserved from harm during peening operations.

Control Console

This cabinet mounted on rollers houses the electronics power supply, high performance computer, LED display monitor, keyboard, mouse, and handheld pulse generator.

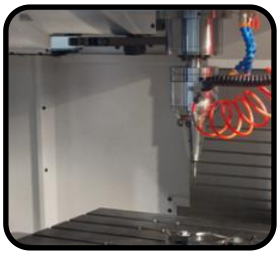
Hand-Held Pulse Generator

Handheld unit with two rotary dials that permit operator to control peening frequency from 20-500 hits per second, and impact force from 0-100%



Workpiece

Any machined component whose surface will undergo the micro cold forging or machine hammer peening process. See 'APPLICATIONS' for examples.



Machine Tool

Any controllable machine or apparatus used to secure the peening hammer in place and manipulate it against the workpiece surface. This can range from a conventional 3-axis CNC milling machine or 2-axis lathe to any custom-designed equipment or robot depending upon the workpiece and application.

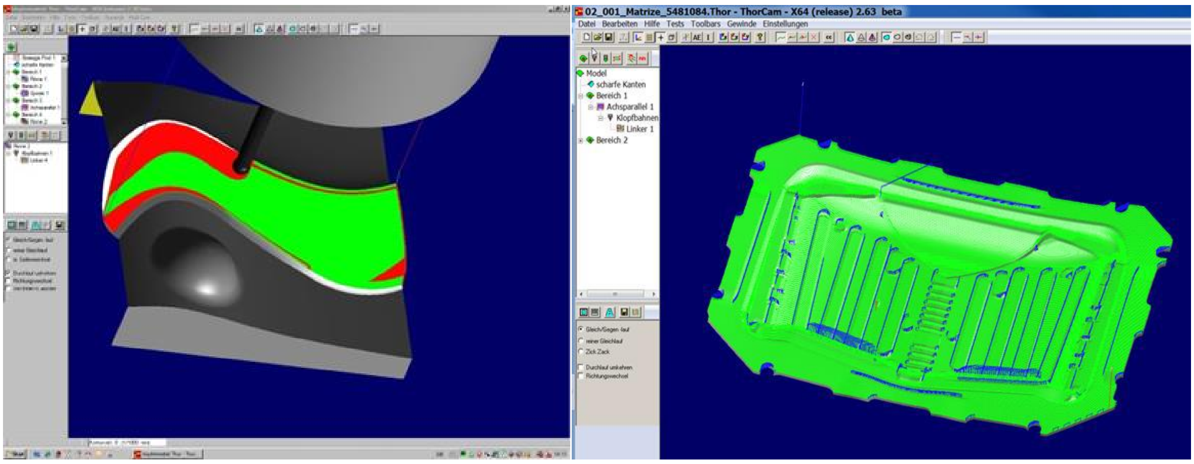
4.2 CAM software of Accurapuls system

To create the peening path, the Accurapuls CAM software is required

The specially designed Accurapuls CAM software is key to achieve best results with peening technology. The accurate process path which is on the true designed 3-D geometrical surface, combined with the right peening strategy, will lead to outstanding final machined surface quality.

The Accurapuls CAM software converts given 3-D-data from various CAD sources (iges, vda, step, …), creates specific process patterns based on own mathematical modelling and generates NC/CNC-codes with which 3-/5-axes milling machines could be controlled.

Highest surface quality is achieved, if all Accurapuls CAM software features are exploited ideally in controlling both: the final machining step and the subsequent peening process.



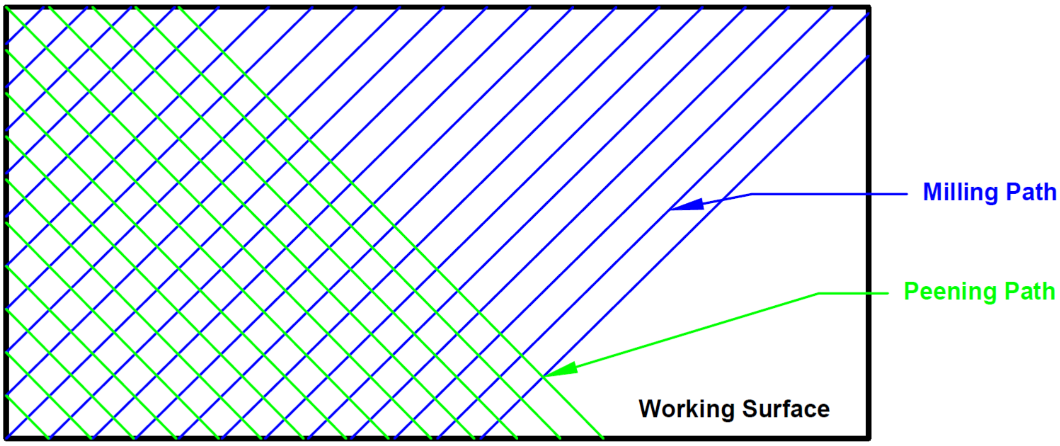
Special features:

The software performs various protection functions:

- Sharp edges
- Small radius
- Railway reversals
- Area borders

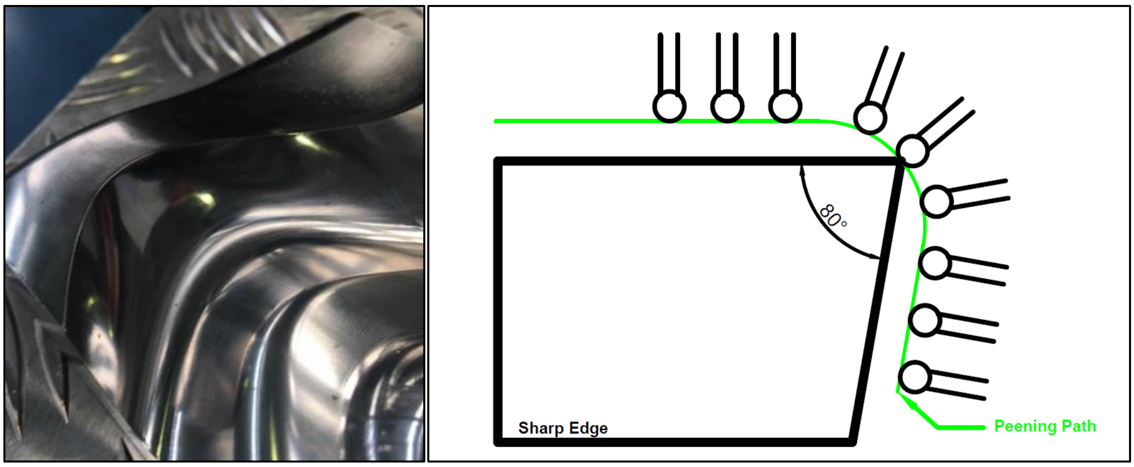
Tapping in steep areas The software generates knock lanes with the necessary impact intensity even in steep areas

- The peening direction is always perpendicular to milling direction



Peening path can be designed automatically by Accurapuls MCF software

- Sharp edge without radius



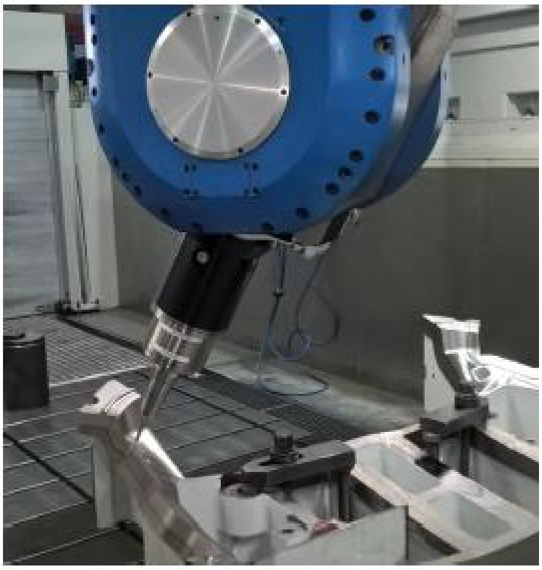
MCF peening only change the metal surface in very small scale, it doesn't damage the sharp edge we need. For sharp edges, the peening stroke will be automatically shorten to reduce peening force. When the peening ball arrives the edge top, the stroke is zero and the peening force is also zero.

4.3 Realized installations in industry

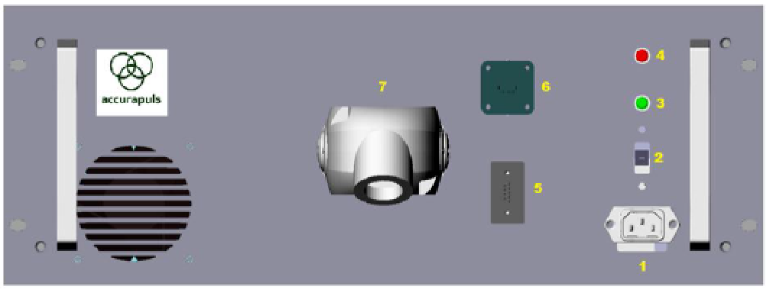
Accurapuls hammer peening system has two kind of installation methods available:

Fully integrated

- BMW Dingolfing and BMW Munchen:
  Fully integrated MCF system/FOGL milling machine with automated interchangeable spindle unit.

MCF hardware is mounted at an cartridge which could be fixed at the machine head with internal supply of media (power and air). Control unit is installed in control cabinet of CNC-machine.



1 Power 230Volt
2 Switch on/off
3 Control-lamp green
4 Control-lamp red
5 Profibus Interface
6 Ethernet Interface
7 Plug for MCF-Hardware

Semi integrated

- BMW Eisenach: semi integrated MCF System at T25/D+R milling machine, outside supply of power & air, control unit of MCF placed separately

- BMW Dingolfing: semi integrated MCF system jobs ever 7, outside supply of power and air, control unit of MCF placed separately

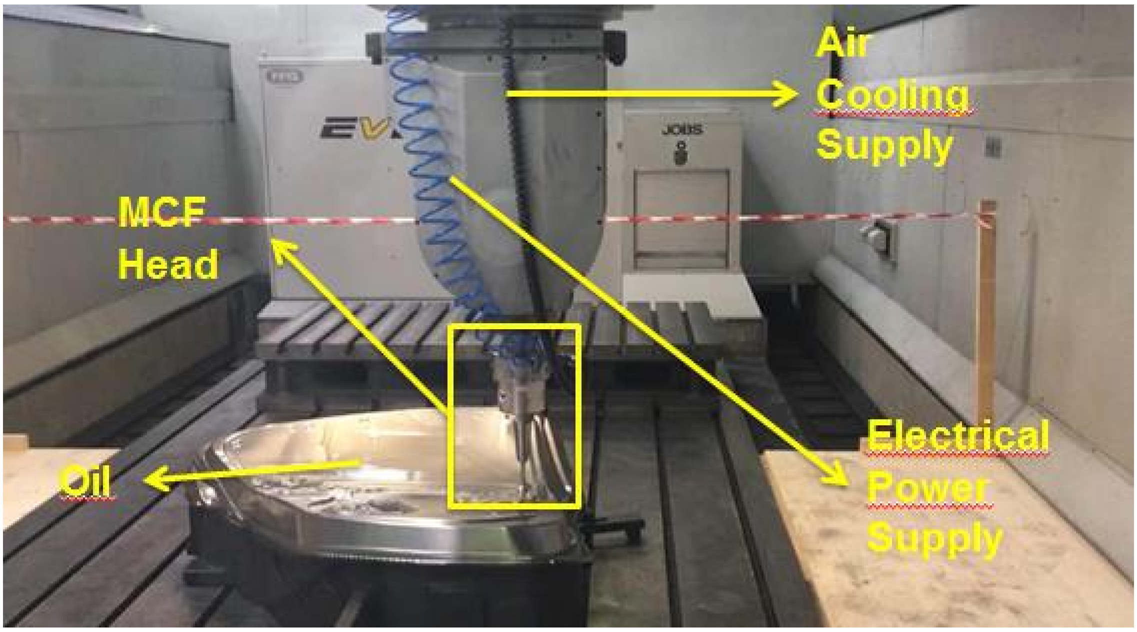
BMW Eisenach BMW Dingolfing

4.4 Installation opportunities

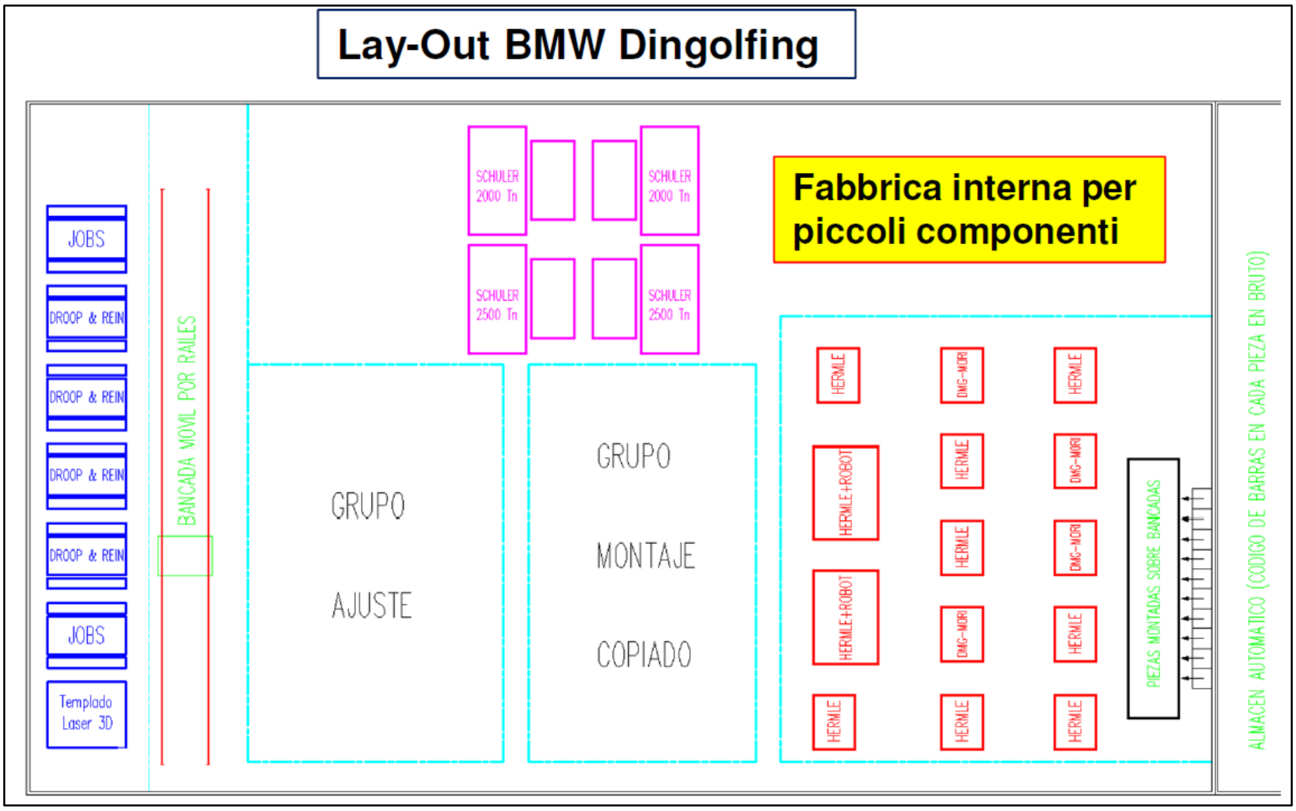
The work group can be installed in an integrated way with the CNC machine with an appropriate adapter and can be used as an interchangeable tool, with the software integrated into the computer on board the machine, or semi-integrated, with an external air and current outlet. external hardware station that can be connected to the CNC control center.

- The hammering head has a frequency of about 200 strokes / sec., With adjustable stroke according to the hardness of the materials to be processed.
- 230V operating voltage with power consumption from 1.2 to 1.6 Kw.
- It is necessary to use specific (more compact) cast iron for the hammering, in which there is no possibility of porosity or imperfections, which would be highlighted by this type of processing.
- No constraints regarding steels.
- It is preferable to perform machining on materials already hardened (laser hardening).

- It is always necessary to treat the surface to be treated with lubricant (Spray) to avoid color variations due to different feed speeds.
- According to the above, the finish of the surfaces before the hammering can be performed with a wider pitch, up to 0.5mm with consequent reduction of the machine time (currently in FCA a final pitch of 0.2mm is used).
- Former head of mold manufacturing at the now-retired BMW Dingolfing plant, the manual polishing time of the mold, by his experience, is 10% of traditional polishing.
- It is always necessary to treat the whole surface to be treated with hammer peening with a spray lubricant to avoid different colors on the surface according to the different working angle and to avoid any scratches due to rubbing of the sphere on the piece.
- The casting must be appropriately prepared by the foundry with cooling control to be homogeneous in the hardness (impurities create soft areas and deformations as a result of the hammering), the cost of mergers will be greater (argument already dealt with Massifond), it has been reported that this problem was managed by BMW as a commercial agreement (+ mergers but at the same price).
- The diameter of the sphere is chosen by the program according to the particular to be worked (more or less complex shapes) a sphere of 6mm has a contact area of 0.6mm, it is very important to have a high frequency and a low feed to get a good quality of the surface.



4.5 Benchmark of other die makers



With the benchmark of BMW Dingolfing die shop, we can see they put all machining operations in line, including polishing and laser hardening, fully automatic. Their equipment and layout strategy is following:

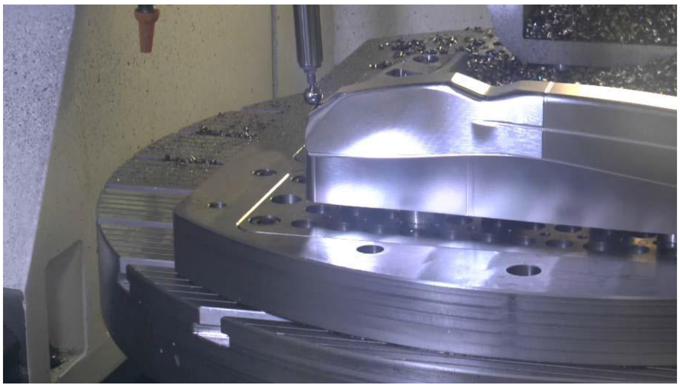
The palletized system is about 120 m in length. All machining activities can be done in plant. It's a large saving of time.

In BMW die shop, the previous polishing process is the same with ours, which is:

- Time-consuming finishing of surfaces by hand with honing stone and sandpaper
- The result depends on the personal experience and crafting skills of each employee

But now they use a new technology called hammer peening to perform the polishing.

This micro-forging technology to crush ridges produced during copying allows a high surface quality and reducing polishing times.

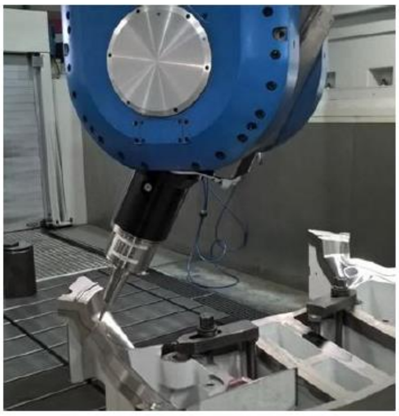


BMW apply this technology at 3 locations:

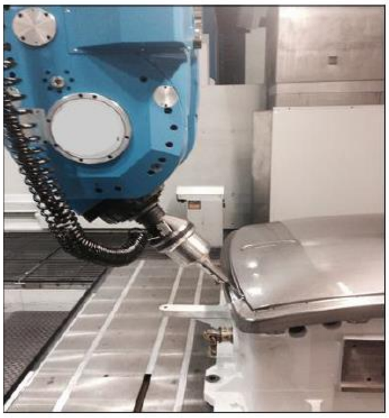
- Dingolfing: automatically changeable spindle unit with fully integrated peening module on the FOGL milling machine.
- Munich: automatically exchangeable spindle unit with fully integrated peening module on the FOG milling machine.
- Eisenach: adaptive peening module on the T25 milling machine.

Dingolfing
Automatisch wechselbare Spindeleinheit mit vollintegriertem Klopfmodul auf der FOGL Fräsmaschine

München
Automatisch wechselbare Spindeleinheit mit vollintegriertem Klopfmodul auf der FOG Fräsmaschine



Eisenach
Adaptives Klopfmodul auf der T25 Fräsmaschine



<u>Evolution of the process chain of a draw die:</u>

Manufacturing process without hammer peening:

Manufacturing process with hammer peening:

Manufacturing process with hardening hammer peening:

<u>Results of surface quality:</u>

Surface visually assessed:

- The hammer peened surfaces are of very good quality
- The dies are installed in the Try-Out press without reworking
- First attempts can be made immediately

Surface measured:

- Rz 4µm to Rz 7µm
- Spread across all components

Comparison:

- A hand polished outer skin surface reaches Rz 3µm to Rz 4µm

Tip: difference between the two surface roughness indicators Ra and Rz

Ra is calculated by an algorithm that measures the average length between the peaks and valleys and the deviation from the mean line on the entire surface within the sampling length. Ra averages all peaks and valleys of the roughness profile and then neutralizes the few outlying points so that the extreme points have no significant impact on the final results.

Rz is calculated by measuring the vertical distance from the highest peak to the lowest valley within five sampling lengths, then averaging these distances. Rz averages only the five highest peaks and the five deepest valleys. Therefore, extremes have a much greater influence on the final value.

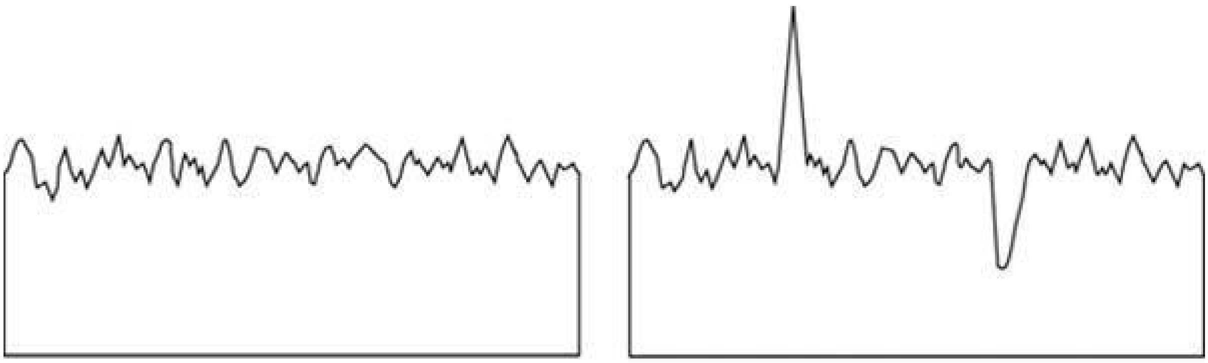


Figure: Ra1=Ra2, Rz1<Rz2

Figure: Die surface after finish milling and hammer peening

Results of try-out:

The first drawing attempts with hammer peened draw dies consistently yield very good results.

- The hammer peened surfaces are ideally suited for the deep drawing process.
- The hammer peened dies correspond exactly to the virtual forming simulation.

Advantages in die manufacturing process:

- Innovative finishing for surface refinement
- Industrial production of tool components
- Standardized and reproducible surface quality
- Digitization to the last process step> CA original tool component corresponds to simulation status
- Reduction of quality loops
- Optimal triplogic condition for the thermoforming process
- Detailed planning of the manufacturing process
- Substantial reduction of cycle time in the manufacturing process

Examples on active execution times:

BMW has requested as a goal that the time of the car machining should not change, new milling time + hammer peening time = initial milling time, making the drill finish poorer and recovering with hammer peening machining, so you have the saving most of the manual activity (90%). BMW applies this technology frequently on loose and pre-assembled flanging / trimming blades, but does not apply hammer peening to a blank holder which is only touched manually and by press.

With a 60h milling time to work with 0.2 milling step, we move to a step of 0.5 (this results in a saving of 2/3 of time) and therefore with execution times are reduced to 20h (savings of 40h), then the active hammer peening requires 20h, as a result it goes from a 60h to 40h only in the machine phase.

Besides hammer peening technology, we can see BMW die shop perform all heat treatments by laser in the manufacturing line. Therefore, all of activities can be done at home.

The lower punches and shear punches do not harden until the trimming has been done and adjusted.

Figure: 3D laser welding in BMW

4.6 Benefits of Accurapuls system

Replacement of manual polishing:

The Accurapuls system of peening can replace in most of the cases the manual and cost intensive process of polishing. The total cycle time can be reduced significantly, surface roughness of less than 0,3 µm can be achieved, while total reproducibility, true to size and security of operation are guaranteed.

Higher savings through longer lifetime:

Mechanical components and tools perform much longer after treatment with the Accurapuls system of peening. Reasons are the induced inherent compressive stress, which leads to higher hardness of the surface layer combined with the CNC polished surface. Secondary costs for unplanned down times, spare tools and parts can be minimized by the use of the Accurapuls system of peening.

Low complexity of integration:

The Accurapuls system of peening compared to other technologies is easy to integrate into the existing workflow.

Increased process safety and stability:

Specifically developed Accurapuls CAM software assures absolute reproducibility and sound operations.

Die making process improvement with Accurapuls MCF

Before	•Manual milling •Manual polishing
1980	•CNC milling •Use CAD/CAM data for programming •Manual polishing
1990	•HSC (high speed cutting) milling •Use CAD/CAM data for programming •**Manual polishing**
With MCF	•HSC (high speed cutting) milling •Use CAD/CAM data for programming •**Use CAD/CAM data for micro-cold-forging**

Summary of Accurapuls hammer peening system

1) Increase quality of finish
2) Replacing the manual work increase process reliability and repeatability
3) Faster Try-Out process
4) Higher predictability of the production process
5) Increasing tool life by introducing compressive residual stress
6) Significant reduction of the total cost in the tool making
7) Return on invest after a few sets of tools
8) Tools that are processed with the MCF correspond during the real sheet metal forming process to a higher degree (95%-97%) to the FEM sheet metal forming simulation

Chapter 5 Optimization opportunities of die manufacturing process

5.1 New manufacturing workflow

My recommendation for FCA Mirafiori die shop is to apply both Accurapuls hammer peening technology and internal laser hardening to replace current manual polishing and external heat treatment. The optimized manufacturing workflow from casting to delivery is following:

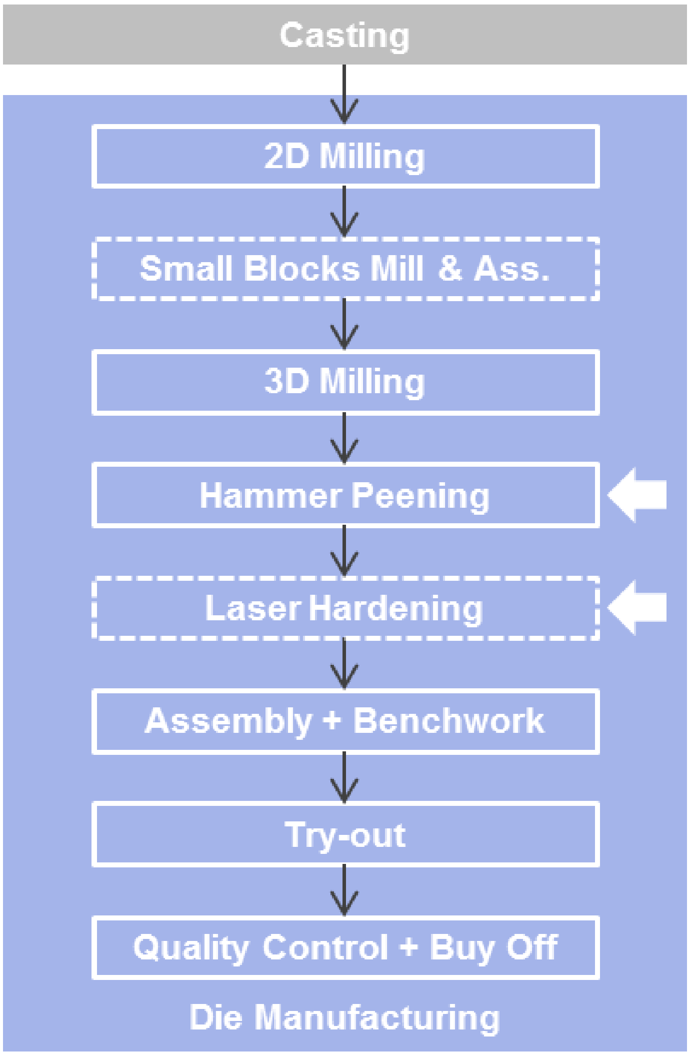


Figure: New manufacturing workflow

Comparing to the old workflow, due to the external heat treatment is eliminated, all manufacturing activities can be done inside our die shop, this will be a giant benefit for the production process predictability. Using hammer peening technology, we can minimize the manual work, Improve the die surface roughness and make the die surface more correspond to the FEM simulation result. But after we adding two new operations, the plant lay-out, the total working hours and costs will be changed. We should make further discuss.

5.2 New machining area lay-out

For laser hardening, the common way is to use an separate 3D laser machine after machining activities as we see in BMW die shop. For hammer pening, Accurapuls has two implement methods:

- Integrate the hammer peeing head with current 3D milling machine. The advantage is we don't need to buy a new machining center which costs a lot, don't need to change current plant lay-out and FMS. However, if the new operation occupies current milling machine, there will be a negative influence on our production capacity and time to market. What's more, the high working frequency of the hammer peening head may damage the milling machine, Influencing the machining accuracy.
- Buy a new machining center specifically for hammer peening and extend the flexible manufacturing system.

Therefore, we need to make a trade-off between these two methods. For FCA, we decide to add automatic hammer peening system integrated with a new CNC machine and laser hardening system two work stations to extend the FMS.

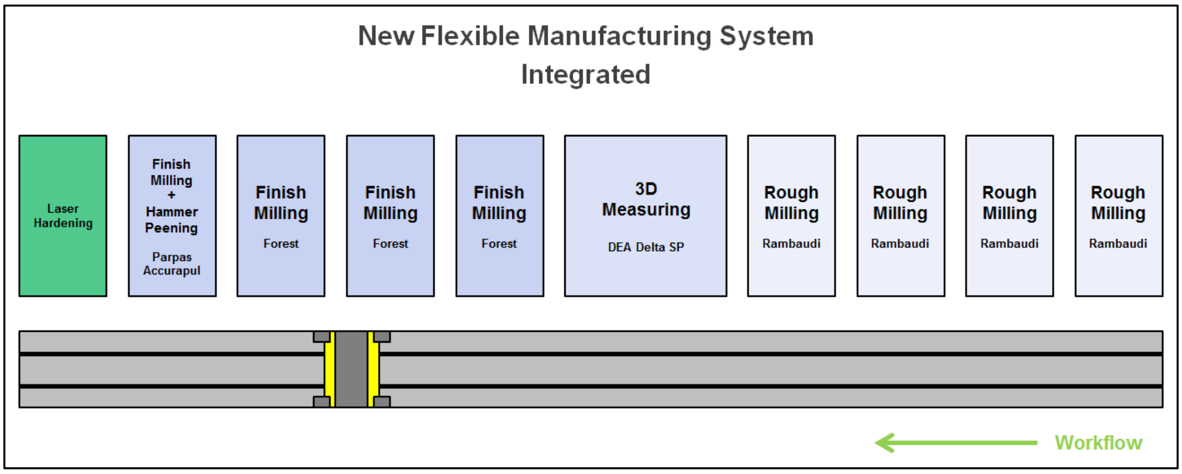


Figure: New FMS with integrated hammer peening system

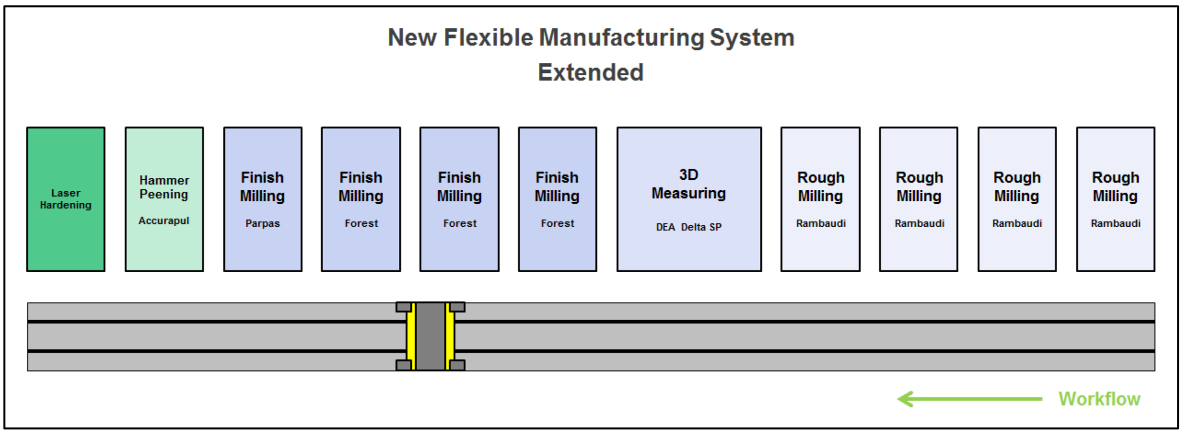


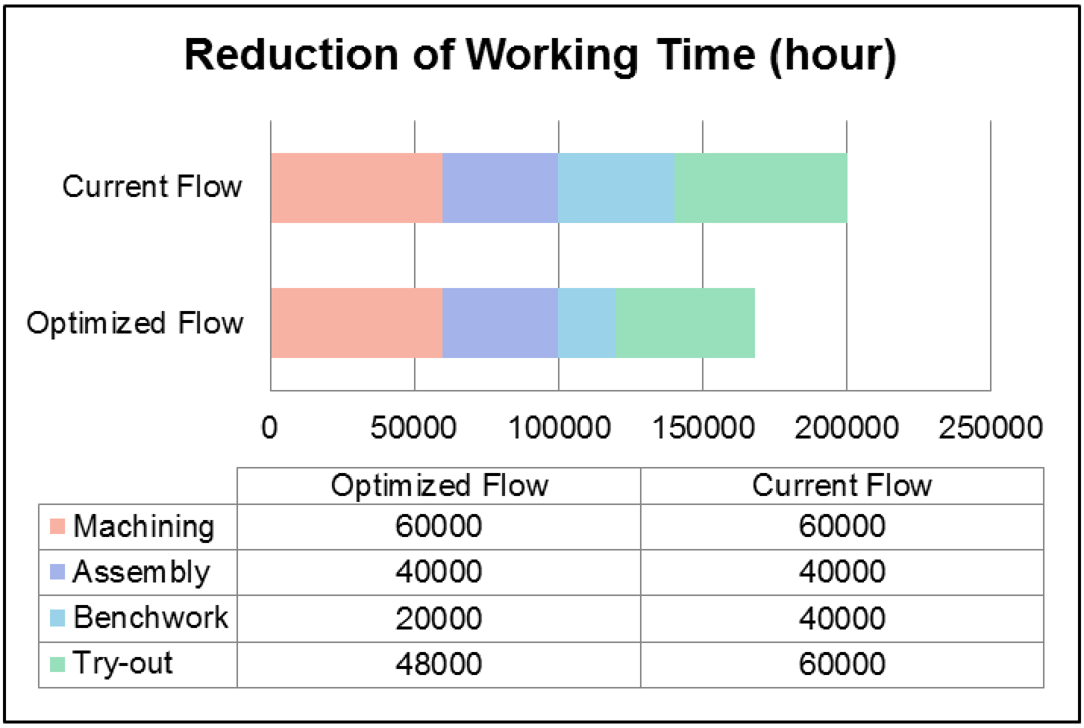
Figure: New FMS with separated hammer peening system

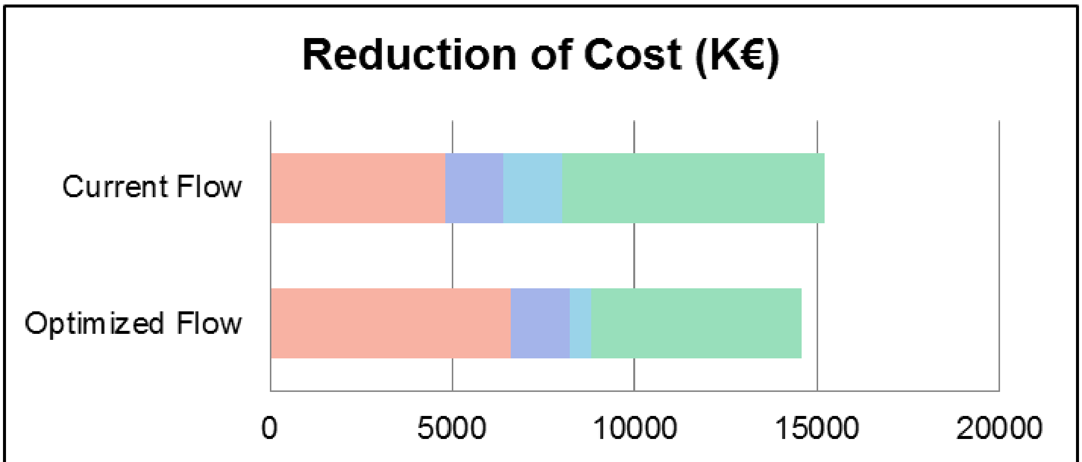
5.3 New working hours and costs

Following table shows a calculation of the changes in working hours and costs before and after applying hammer peening. We don't talk about laser hardening in this calculation.

Our current working hour is 200,000 per year. According to the test and benchmark of Accurapuls hammer peening system, the working hour of machining with hammer peening is no longer than the previous machining working hour without hammer peening, so we assume it is the same before and after. We also assume the working hour saving ratio of benchwork and try-out depending on our experience and the better polishing result obtained by hammer peening. The machining cost will increase and the benchwork cost will decrease.

	Manufacturing Activity	Working Hour Ratio	Working Hour (before)	Saving Ratio	Working Hour (after)
Time	Machining (+hammer peening)*	0,3	60000	0	60000
	Assembly	0,2	40000	0	40000
	Benchwoek (+manual polishing)**	0,2	40000	0,5	20000
	Try-out	0,3	60000	0,2	48000
			Total Working Hour (before)		**Total Working Hour (after)**
			200000		168000
			Total Working Hour Saved	**Saving Ratio**	
			32000	16%	
	Manufacturing Activity	**Cost per Hour (before)**	**Cost (before)**	**Cost per Hour (after)**	**Cost (after)**
Cost	Machining (+hammer peening)*	80	4800000	110	6600000
	Assembly	40	1600000	40	1600000
	Benchwoek (+manual polishing)**	40	1600000	30	600000
	Try-out	120	7200000	120	5760000
			Total Cost (before)		**Total Cost (after)**
			15200000		14560000
			Total Cost Saved	**Saving Ratio**	
			640000	4.2%	
Note	*Before without hammer peening, after with hammer peening				
	**Before with manual polishing, after without manual polishing				





	Optimized Flow	Current Flow
Machining	6600	4800
Assembly	1600	1600
Benchwork	600	1600
Try-out	5760	7200

From above calculation we know that we can save 32000 hours and 640000 euros per year.

Actual running cost

In addition to the cost calculated above, we should also take into account the other costs during the running of hammer peening system, which are:

- License cost: first year free and from the second year 10000 euro/year.
- Maintenance cost: every 500 hours of work (guaranteed for the first 2000h) 1500 euro for ordinary maintenance services performed by Accurapuls.
- Casting cost: to obtain a better hammer peening result, the casting material and method need some change.

Yearly Cost Saved(before)	640000
Yearly Maintenance Cost	180000
Yearly License cost	10000
Increasing Casting Cost	10000
Yearly Cost Saved (after)	440000

After removing these running cost, the actual cost saved per year is 440000 euro.

Investment recovery

One-time investment costs for Accurapuls hammer peening system:

- Machinery cost: 200000 euro includes 2 heads, amplifier, software and pc (with commensurate hardware to be checked with IT for compatibility).
- Extra cost of training for the use of equipment and the execution of toolpaths

- Extra cost for adaptation modifications on machines: the head loaded on the spindle bearings, can be mounted on the electro-spindle only if it is properly sized.
- Cost of New machining center (if needed).
- Cost of extend FMS (if needed).

Our total investment budget is 1.5 million euro. According to above calculation, we can recover our investment within 4 years.

5.4 Conclusion

In order to enhance the die surface roughness and optimize the die manufacturing process, we have studied four alternative technologies, they are SandRob, SemaTeck and Accurapuls. After studies in their roughness result, feasibility to automotive dies, application in industry, time saving ability and cost, we suppose Accurapuls hammer peening system is the best opportunity we need.

Using this technology, we need to change our current die manufacturing process that add hammer peening after the final milling. And we have to extend our flexible manufacturing system to install this equipment (Accurapuls integrated with CNC machine).

Then, we can obtain mainly four benefits:

- Die surface roughness of less than 0,3 µm can be achieved. Hammer peened die surface are almost exactly (95%-97%) in line with the FEM simulation result.
- Significant reduction (16%-20%) of manufacturing time. Higher working time predictability without manual operation.
- Reduction (2.9%) of manufacturing cost. Investment for the hammer peening system can be recovered in 4 years.

What's more, from the experience of other die maker, we learned that all hardening activities can be replaced by laser hardening. Using this strategy, all manufacturing operations from casting to try-out can be done inside our die shop to optimize the die manufacturing timing.

Acknowledgement

I would like to express my great appreciation to professor Renzo Franco Giraudi, my thesis supervisor, for giving me the opportunity to write this thesis in FCA die shop and for his advice and assistance in keeping my progress on schedule. His willingness to give his time so generously has been very much appreciated.

I would also like to extend my thanks to the colleagues in FCA die shop, especially to Mr. Corrado Forestieri, Mr. Pietro Tarantino and Mr. Alberto Pelisseri who offered me most of the knowledge and materials in die technology, die engineering and die manufacturing respectively. Without their passionate explanation and guidance, this thesis could not have been successfully conducted.

Finally, I wish to express my gratitude to my family in China and to my friends in Italy, for providing me with unfailing support and continuous encouragement through my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.