The present invention relates to a precision-forging parts manufacturing process including the manufacture and development of a first forging tooling equipment, the forging of the parts with said tooling equipment, whereas the parts have a determined excessive thickness, and their finishing treatment.

The method is characterised in that it also includes the realisation of a digital model of the surface of the first tooling equipment, the forging of parts, the rehabilitation of the tooling equipment or the manufacture of new tooling equipment from the digital model, after forging a determined number of parts.

In particular, the parts are subjected to a finishing treatment directly after forging, said treatment including mechanic polishing.

The invention applies to the forging of blades for turbo machines.
The present invention concerns the field of precision forging of metal parts and in particular of complex and awkwardly-shaped parts, such as large-sized blades for turbo machines.

For manufacturing metal parts, forging techniques are preferably implemented when they should absorb significant loads during operation. Such is the case for compressor blades or turbo-jet engine blowers for which the internal loads are generated notably by the vibrations and the centrifugal forces to which they are subjected.

Forging consists in deforming plastically a block of metal by imparting shocks or applying a pressure. The process is generally composed of several steps, while forming successive blanks, which come gradually closer to the finished part. If required, the forging of the part is completed by a calibration phase leading to more accurate shapes.

For compressor blades, for example made of titanium, an operating mode comprises the steps of upsetting, extrusion and stamping, out of bars.

Before the upsetting phase, the metal bars are prepared by undergoing an enamelling operation. It is a glass-based coating whose purpose is to facilitate the flow of matter into the tooling equipment. It also serves as thermal insulation while maintaining the temperature during the transfer from the oven to the press and while preventing any thermal shocks when the part contacts the tooling equipment. Its function also consists in protecting the part against oxidation. According to a preferred embodiment, the coating is sprayed electrostatically on the parts before loading into the oven.

In parallel, the internal surface of both shells or upsetting tools are lubricated. The upsetting phase consists in pushing the end of the bar, raised to a temperature ensuring good ductility, by means of a punch towards the inside of the cavity formed by both shells. When the shape of the part requires so, the upsetting is performed in several successive steps in suitable tools. For example, this process may be appropriate to form the feet of compressor blades as well as, if needed, the fins.

Between each upsetting step, the enamel coating, which has warped, as well as the scale generated, must be eliminated using appropriate baths, before building a new coat of enamel.

According to the type of part, for compressor blades for instance and not for blower blades, the upsetting is preceded by an extrusion step. Such step consists in stretching the metal slug through a die, whereof the profile corresponds to that to be realised.

Once the parts have been pre-forged thus, they are forged into given shapes by stamping dies.

This mechanical forging operation consists in elaborating a part by forcing a blank thereof to fill in, by imparting shocks or by applying pressure, a print engraved in a stamping die corresponding to the shape of the part to be obtained. In the case of titanium, its yield stress depending highly on temperature, the forging is performed in hot condition up to a certain limit imposed by the structural evolution of the material which alters the mechanical properties thereof.

For a compressor blade or a blower blade, a known shaping operation includes two stamping operations:

A predefinition stamping which preforms the foot, and the fin if required, and starts to crush the blade by turning the bar from a rounded shape into a flattened shape.

A finishing stamping operation, which completes the forging cycle with displacement of matter and brings the part as close as possible to its final geometric form before machining.

The stamping operations are carried out on hydraulic or screw-type presses whereof the stamping dies are pre-heated. Under such conditions, the forging time is relatively short to avoid too rapid cooling down of the part and excessive heating of the stamping die by thermal conduction between the part and said stamping die inasmuch as the temperature of the tooling equipment differs from that of the part. Besides, by reason of the high level of stresses to which it is subjected by contacting the part, a lubricant is applied to the engraving of the stamping die to slow down the cooling process of the part, for easier flow of matter and to reduce the forging loads.

Once the part has been forged, it is machined and polished to final sizes. Such operation is made necessary by reason of the excessive thickness remaining after forging. In fact, the engraving of the stamping die is determined in order to keep the excessive thickness of the part. After forging, machining and polishing enable to give the finished part the precise shape and the surface condition requested.

For parts made of titanium, notably, polishing is an important operation. Its purpose is to eliminate the defects resulting from the forging operation and which are liable to give rise to developing cracks.

The present invention relates first of all to the development of tooling equipment which are the stamping dies and the shells introduced above. There is a need, indeed, to improve these operations which have a negative contribution to the global economy of this technique.

The time required for the realisation of the tooling equipment, according to the conventional method, is rather long since successive retouching operations are compulsory.

Indeed, the print of the stamping die has not rigorously the shape and the sizes of the raw forging part to be obtained. It departs therefrom by "corrective terms" which compensate for elastic-plastic deformations of the tooling equipment during the forging cycle. We do not know exactly how to forecast such corrective terms and it is therefore necessary to retouch the stamping die further to the measurements taken on the test pieces obtained. In so-called "precision" forging, excessive thicknesses are small, for example 0.8 mm, so that the finished part may be obtained by polishing the raw part using a grinding belt or, if needed, notably if the part is made of titanium, by the combination of chemical machining and grinding belt polishing. Such is the case for the airfoil part of blades.

Developing a precision forging stamping die is consequently a long-winding and costly process, since it calls for numerous retouching operations, interlaced with forge-testing of parts.
Retouching cannot be performed rapidly since it requires forging tests with each time the steps of heating and assembling the tooling equipment on the press, the realization of a few parts, the calibration and the control of these parts. Besides, tests parts are generally not usable; they are wasted in most cases. During the testing and retouching operations, it should be noted that means such press, stamping die conveyor belt, control instruments, are unavailable for production.

It should also be noted that, according to this conventional method, it is practically impossible to obtain two identical pieces of tooling equipment, either stamping dice or shells.

This lack of accuracy in the definition of the tooling equipment translates by a lack of regularity in the products manufactured by means of said tooling equipment.

Once the stamping has been adjusted, i.e. once the raw forging test parts obtained have the shape and the sizes required, such stamping die can be put into service in order to manufacture series parts. The stamping die degrades gradually in operation, and it becomes necessary, for example after 1000 to 5,000 parts as the case may be, to rehabilitate the stamping die or to use another.

The rehabilitation of a degraded stamping die consists, according to a first method, in reloading the zones wherefrom matter has been torn off and in machining and polishing a new print. According to a second method, the print is reconstructed completely by machining, after having eliminated the nitrided layer and removed a thickness of several millimetres of matter. This technique is designated as rewashing. The rehabilitation of a stamping die or the manufacture of a new stamping die require the same adjustments as the initial stamping die. They are consequently also long and costly.

Finishing by abrasive belt polishing on a five or six-axis type machine is well suited to complex-shaped parts such as blade airfoils. Unlike a machining operation, for example by milling, abrasive belt finishing removes, at each pass, a pre-established thickness of matter, said thickness increasing with the speed of the abrasive belt and the pressure exerted by the belt on the part, said thickness decreasing with the forward speed of the belt with respect to the part. The shape and the sizes of the part after an abrasive belt pass depend therefore directly on the shape and the sizes of the part before said pass.

This does not cause any problem with the first parts produced from the stamping die, since they are all identical. However, as the forging continues, degradation of the stamping die can be noticed (wear, plastic deformation, etc.)

Parts are sampled for regular checking purposes. When the sizes of the part reach a defined degradation threshold, the tooling equipment is rehabilitated or new tooling equipment is manufacture. The parts obtained with the new stamping dice or the rehabilitated stamping dice may require several finishing passes, separated by measurements, so that they are rigorously identical to the parts obtained with the first stamping die. This similarity in results is particularly important in the case of blade sets on a turbo-jet engine rotor stage.

The problem to be solved is to reduce the finishing cost and to obtain rigorously identical parts although they may have been forged with different stamping dice. It also consists in avoiding wasting parts because they do not meet the specifications, which in the case of precision forging is an important criterion for validation of the process.

According to the present invention, this problem can be solved with a precision-forging parts manufacturing process including

- the manufacture and development of a first forging tooling equipment,
- the forging of the parts with said tooling equipment, whereas the parts have a determined excessive thickness, and
- their finishing treatment.

This method is characterised in that it also includes the following steps

- the realisation of a digital model of the surface of the first tooling equipment,
- the forging of parts,
- the rehabilitation of the tooling equipment or the manufacture of new tooling equipment from the digital model, after forging a determined number of parts.

Advantageously, the parts are subjected to a finishing treatment directly after forging, said treatment including mechanic polishing.

In particular when the parts are made of titanium, the finishing treatment comprises a combination of mechanical polishing and of chemical machining.

Chemical machining consists of chemical dissolution of the titanium alloys. Matter removal is conditioned by the soak time of the parts.

The method according to the invention is remarkable in that:

- a) The first stamping die is in particular adjusted so that the raw forging part has an excessive thickness liable to be removed by a mechanical polishing and/or chemical machining operation in a single pass or at least without resorting to significant manual retouching operations.
- b) When the first stamping die is adjusted, the position of a determined number of points on the surface of the print is acquired digitally and a model of said surface is digitalised.
- c) The manufacture if new exchange stamping dice includes a finishing machining operation so that the digital model of their print is identical to the digital model of the print of the first stamping die.

Preferably, polishing is automated thanks to abrasive belts. Advantageously, a machine exhibiting a contact wheel system driving an abrasive belt is used. This type of machine advantageously enables controlling the removal value and the surface condition requested, on the basis of simple machine parameters such as the load exerted by the contact wheel on the part, the running speed of the belt on the contact wheel as well as the relative displacement velocity of the wheel with respect to the part to be processed.
This process enables to master the excessive thickness removed and to reduce considerably the number of successive finishing staples after forging. The geometry of the part as well as its finishing surface condition are ensured, with a minimum of manual retouching operations, let alone, no such retouching operation at all.

Other features and advantages will appear in the following description of the method of the invention with reference to the figures whereon

FIG. 1 represents a stamping die,

FIG. 2 an upsetting shell,

FIG. 3 a belt polishing machine.

As can be seen of FIGS. 1 and 2, the tooling equipment involved in the forging method of the invention, regardless whether it includes a blade forging stamping die 20 or an upsetting shell 30, is complex in shape with, additionally:

- warped and twisted zones, highly bent,
- very little bent,
- deep and narrow, for example a depth of 100 mm with a width at the bottom of 20 mm,
- composed of planes, cylinders, cones and fillets between surface portions,
- and significant variations in altitude between both sides of the tooling equipment.

The stamping die degrades gradually by wearing the print, notably, and by plastic deformation. When the degree of degradation reaches a pre-established threshold and that renewal of the tooling equipment is considered necessary, said equipment is rehabilitated or new tooling equipment is manufactured on the basis of information saved on the tooling equipment adjusted previously. Continuity of the method is thereby ensured.

After having adjusted first tooling equipment to the final sizes, a digital model of such tooling equipment is realised. The means of implementation of this digital model of the tooling surface are known by themselves and available on the market.

The items most frequently used in the industry are contact sensors that can be found on three-dimensional measuring machines (MMT). Because of the spherical shape of their ends, such sensors provide results which ought to be subjected to a radius correction calculation.

Among the contact free sensors, the most current ones are those based on optical techniques with one or several laser sources or laser free optical techniques. Both use the measuring principle based on trigonometry and more particularly on triangulation.

In the case of a technique with laser sources, the part is illuminated by a coherent light source, a laser beam generally, and one or several CCD (charged coupled device) type cameras observe the scene from an angle which is different generally from that of the emission. After a calibration phase of the cameras, the coordinates of the points of the object are deduced from those of its picture on the CCD array of the camera.

In the case of a laser free technique, the principle is based upon the projection, onto the part, of a regular grid, a fringe network, then the calculation of the superficial points of the object by triangulation.

Once the sensor has been selected, one should define the 3D-digitisation strategy which consists in:

1. finding one or several positions of the sensor(s) which enable realisation of the digital model of all the surfaces of the part to be accessed;
2. choosing a density of the cloud of points according to the task to be performed then, from said result, such as rapid prototyping, surface reconstruction or visualisation.

For all forging tooling equipment, a precision of acquisition of the order of 0.02 mm, for instance, is required.

If needed, according to the complexity of the geometry of certain portions of the surface, the geometry of the surface follows a reconstruction stage. Such operation may be carried out by data-processing means known to the man of the art.

First of all, the cloud of points obtained by digitisation is collected. According to the quality of this cloud of points, it may be necessary to apply a filter thereof whereof the purpose is to attenuate the multiple small local variations, while eliminating aberrant points, measuring errors, etc.

Reconstruction is performed on the basis of this processed cloud:

For the reference zones (planes, cylinders, spheres), the shape is reconstructed automatically.

Failing which, a surface is reconstructed which covers "at best" a selection of points delinated by its boundaries. The latter may be boundaries of elements which have already been reconstructed, curves plotted on the cloud of points, theoretic elements. Upon completion of the reconstruction of each square, the software enables analyses over the reconstructed surface (maximum deviation, maximum distance between the boundaries of two adjacent squares . . . ). This analysis enables the operator to modify the reconstruction parameters (mathematic definition parameters, surface tension, boundary curvature . . . ).

When the digital model is performed, it is saved under a CAD file format to be importer into the CAM environment in order to generate the manufacturing strategy, then a digital programme on a machining tool, for example a UHS high-speed type machining tool.

This programme is then used for the manufacture of new tooling equipment, stamping dice, so that they are rigorously identical to the perfect initial tooling equipment.

In the case of "rewashed" or new tooling equipment, verification is conducted by comparison between the CAD model of the perfect tooling equipment and the cloud of points derived from digitalisation of the tooling equipment manufactured.

There is described thereunder a finishing method after abrasion forging by means of a six-axis type polishing machine.
The geometry of the part is controlled by a multi-dimensional-type technique and the thicknesses and the geometrical shapes are re-balanced over the whole blade by combination of weak point masking using an adhesive tape and chemical machining.

Then the excessive thickness of matter is removed and the final surface condition of the blade, requested on the plane of definition, by automated polishing on six-axis polishing machines. There is described below the method according to the FIG. 3 showing a six-axis type commercial machine.

The machine comprises a frame 1 with a parts support 2, a compressor blade for example, which is held horizontal along its main axis, by means of a mechanic or hydraulic flanging device. A first engine 4 ensure rotational position (rotational axis U) of the part around its main axis. A second engine 6 ensures displacement of the support of the part along a translation axis (x). A third engine 8 drives the abrasive belt mounted on a contact wheel 10 and stretched by a system of rollers.

The rotational axis of the wheel 10 is moreover positioned in translation along both axes (y and z) perpendicular to the first axis x and in rotation along both their associated rotational axes V and W.

The contact surface of the wheel is held constantly in tangential position in relation to the surface of the part.

According to an embodiment, a wheel of 25 mm in width with 120 mm in external diameter is used. Superficially, grooves have been provided on sufficiently rigid coating; for its Shore hardness is 65.

The polishing operation consists in moving the part along the axis x and rotating said part around its axis. The wheel is held constantly in tangential contact with the surface of the part. The wheel is subjected to a pressure determined by the pressure exerted by a cylinder, a belt velocity determined in order to remove a controlled quantity of matter taking into account the infed of the part with respect to the wheel.

Once the part has exited the polishing machine, it is ready for machining the foot and, if needed, the fin with a blade which meets the geometrical as well as the surface condition requirements.

1. A precision-forging parts manufacturing process including the manufacture and development of a first forging tooling equipment (20, 30),

the forging of the parts with said tooling equipment, whereas the parts have a determined excessive thickness, and their finishing treatment, characterised in that it also includes the realisation of a digital model of the surface of the first tooling equipment (20, 30),

the forging of parts,

the rehabilitation of the tooling equipment or the manufacture of new tooling equipment (20, 30) from the digital model, after forging a determined number of parts.

2. A method according to claim 1 wherein the parts are subjected to a finishing treatment directly after forging, said treatment including mechanical polishing.

3. A method according to claim 1 wherein the finishing treatment also comprises chemical machining.

4. A method according to claim 1, wherein the forged parts are controlled to determine at what time new tooling equipment (20, 30) should be rehabilitated or manufactured.

5. A method according to claim 1 wherein the adjustment of the tooling equipment manufactured (20, 30) includes

   a. digital acquisition of the position of a determined number of points on the surface of the tooling equipment manufactured,

   b. the comparison of the position of the points with the digital model, and

   c. possible correction of the surface of the tooling equipment.

6. A method according to claim 5, wherein the points of the surface are acquired by contact free optical measurement.

7. A method according to claim 5, wherein the points are acquired digitally using mechanical means.

8. A method according to claim 1, followed by elimination of said excessive thickness of the parts by abrasion.

9. A method according to the previous claim wherein abrasion is performed using a belt mounted on a wheel which is pressed against the surface of excessive thickness.

10. A method according to the previous claim wherein the quantity of matter to be eliminated is determined by selecting the machine parameters, namely pressure of the wheel against the surface, forward speed of the belt and displacement velocity of the wheel.