Asnières : Masters of micrometry

.Manufacturing the hydraulic components required for Citroën cars means that every day the giant Asnières plant has to deal with the infinitely small. High-precision work to within one micron is rare in large scale production and requires close collaboration between man and machine

In concrete terms, this type of machining involves precision to within the thickness of a sheet of cigarette paper sliced fifty times across its width. Leaning over his lapping machine, the operator machine polishes parts down to the third decimal point, keeping a close eye on the fourth! Here in the Citroën plant at Asnières, operators work to within one micron : to within a thousandth of a millimetre, when most mechanical workshops make do with one-tenth or one-hundredth. And that precision is achieved daily, with an output of 50,000 parts per day !

What kind of process requires that level of quality? Manufacturing hydraulic components for Citroën vehicles; and in the case of Asnières, the famous suspension systems underlying the success of the marque, as well as the brake and steering systems. All these components have one thing in common: the absence of joints to ensure tightness between moving parts. Friction between any joints would decrease the sensitivity of movement. Tightness is therefore ensured by metal-to-metal joints, by reducing operating clearances to within 3 microns (between 1 and 3 microns), and by virtually perfect surface finishing of parts. The number of parts involved and the quantity of hydraulic components manufactured - 14,000 every day - put the Asnières plant in a class of its own. It provides a major contribution to the identity and renown of Citroën cars, and it is not for nothing that the plant also supplies suspension systems for Rolls Royce.

Man over machine

Machining and assembling mass-produced parts to within one micron requires the meticulous integration of tasks in an automated production control system, The result is that technological and human resources at Asnières are more closely interwoven than elsewhere. But, like a clockmaker making watches, human precision, manual dexterity, visual acuity, experience and know-how are what make micrometric precision possible. The golden rule is self-inspection: the operator is capable of immediately evaluating the quality of the operations he is performing. Initially divided into specialized workshops for each type of machining, the Asnières plant over the years has been transformed with the setting-up of the Plan Mercure. The plan, which provides overall guidelines for the entire Citroën company, has a single aim: competitiveness! As a result, the

plant has been completely restructured in terms of product lines, i.e. compensator meters, pressure generation pumps, height correctors, safety valves, structural parts, brake effort proportioning systems, reverse current cut-out relays and other stiffness control systems. This also means that, except for slicing, quenching and tempering, each of the main hydraulic parts is manufactured separately. There are thus some ten manufacturing islets for each type of component, each integrating an extensive range of operations:

conventional machining, superfinishing, part inspection to within one micron, ultra-sonic washing, assembly, tightness and operational inspections of each completed component. The manufacturing plant currently on stream at Asnières is the result of patiently acquired experience and innovative technical solutions which have been honed down to perfection over the years (see table). Micrometric constraints in mass manufacturing led Citroën engineers to phase out part-matching from 1961 onwards. This technique consisted of high-precision readouts of the diameters of each male and female part manufactured in order to choose and assemble them with the requisite clearance of 3 microns. Not very easy to manage. Since then, thanks to superfinishing and self-inspection, each machining process is tolerance-compliant to within one micron. And male parts are totally compatible with female parts of the same type.

For micron precision, finishing is done using centreless grinding machines.

Multifaceted manufacturing

To fully comprehend the scope and scale of the highly specific know-how involved, take for instance the routing required to manufacture a simple part: the height corrector. The component, which is actually a stop valve, is the prime mover for all the hydraulic components manufactured at Asnières. A circular-grooved cylindrical male slide-valve moves freely with a clearance of between 1 and 3 microns into a female drilled bore of the same diameter. The movement of the slide valve and its grooves in either direction opens or closes hydraulic circuits, connecting the component either with the source of liquid (the oil input supplied by the high-pressure pump) or with the tank return line.

Manufacturing a slide valve with a given diameter begins with a process known as slicing, in other words, the collective machining of slide valves side by side from a Steel bar. Although the machining process is automated, it nonetheless requires a great deal of care by the operators, since this is where the micrometric work which will be performed in the superfinishing shop is prepared. Part inspection is therefore integrated throughout the

manufacturing process and is performed both by the machines and by the men, who also continually oversee the operational quality of the machines. Each team of operators is responsible for material requirements and changing production runs, lathe adjustment and tool grinding. This does not prevent the Quality department from optimizing inspection procedures by regular sampling. Once they have been machined and certified as being tolerance compliant, the slide valves are transferred to the quenching and hardening plant (in this case, for nitride hardening), which gives them remarkable resistance to wear and metal fatigue.

The final stage is the vital process in which parts which have been machined to within one-tenth of a thou are transformed into true slide valves finished to within one micron: superfinishing. This is in'fact done in two stages, finishing and lapping. The aim is to remove from the slide valves a few dozen microns... but not one less or one more!

The finishing processes are carried out on centerless grinding machines, and vary according to the profile and dimensions of the slide valves. On each pass, the machining chip gets smaller and smaller, down from 0.06 mm to 0.04 mm to 0.01 mm. At this stage the part is ready for superfinishing. There are still 5 microns left to be removed before the setting is perfect. This is done by lapping, and the chip now is no more than micron dust. Lapping is performed on the circular plate of the lapping machine, a form of grinding wheel, on which the operator sets out 150 slide valves into the recesses provided for that purpose,

A second rotating plate rolls and polishes the slide valves in their axis rather like ball bearings. The operator, guided by his know-how and the sixth sense born of experience, carries out the inspections he deems necessary as the setting approaches its final development. He also turns the slide valves over in order to correct for the conical effect produced by the lapping process.

Three levels of tolerance compliance have to be attained by the slide valves: 1 micron in diameter, 0.5 microns out-of-shape, and 0.3 microns in surface finish. In order to observe the micron and even lower requirements, inspection to within a tenth of a micron by the measuring apparatus is required. Of course, not only does the measurement have to be precise, but it must also be reliable under workshop conditions. To obtain this, a number of precautions (e.g. avoiding continual variations in temperature) have to be taken. The solution adopted at Asnières is simple and foolproof: the operator compares the part with a benchmark of the same dimension and material, which is regularly checked by the metrology laboratory of the Quality control department.

Citroën AND THE MICRON:
40 YEARS ON

The Citroën plant in Asnières has developed a corporate "micron culture", closely linked to the history of the marque and its celebrated hydraulic suspension systems (which in fact are hydropneumatic, combining a liquid and a gas). As early as 1953 Asnières became familiar with the demands of industrial micrometry by experimenting with the first hydropneumatic suspension system for the front-wheel drive "15 six", the forerunner to the DS. This type of suspension necessarily meant using a high-pressure central pump, at the same time making it possible to extend hydraulic power to braking, steering and clutch system control. The extension was tested, and it worked. In those days, lack of precision in manual machining meant 32 classes of slide-valve and as many cylinder bores had to be matched up, leading to a variance of 32 microns. When the DS came onto the market in 1955, however, the number of classes had already been divided by two. Progress made over the following years was closely linked to developments in fine-machining tools, in particular the lapping machine. In 1960 the first electrolytically-deposited diamond-tipped tools appeared, meaning that only 6 matching classes remained. The following year, the classes disappeared altogether to make way for uniform tolerance-compliant production to within one micron, thanks to the design at Asnières of measurement apparatus enabling precision readings to within a tenth of a micron. Subsequently, Citroën designed and engineered gradual multi-spindle lapping machines for cylinder bores; these were operational by 1964. From that point on, skill in micrometry was a Citroën hallmark. Hydraulic components proved their worth and their remarkable sturdiness, and were later adapted for the GS, SM, CX and BX models, together with the enhancements and upgrades produced over the years, including the introduction of the LHM liquid. The roll-out of the XM and Xantia models has at last seen the coming of hydractive suspension, combining the intelligence of electronics with the comfort, roadholding and safety of hydraulic suspension. In this way, at the leading-edge of automobile design and engineering, Asnières continues to make significant contributions to the corporate image of Citroën and the quality of its cars.

Painstaking methodology

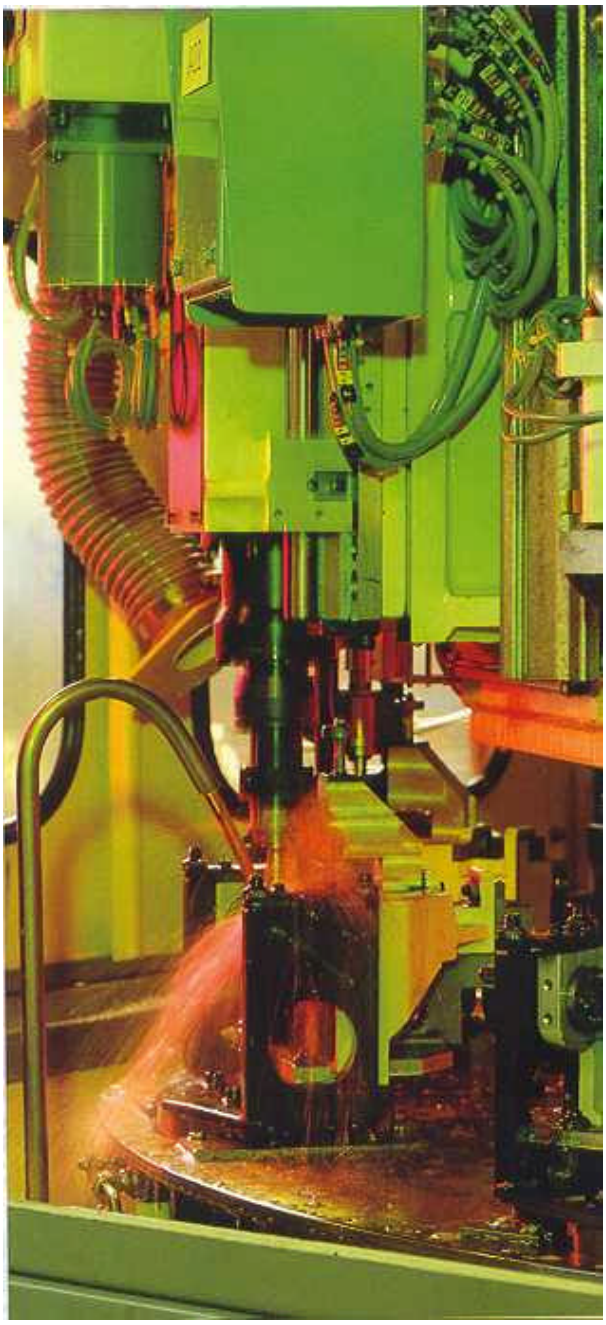
So much for the slide valve. What remains to be explained is how we manufacture its counterpart, the cylinder bore, before the two components are coupled together to form the pressure distributor. This in turn will be integrated, for instance as the main component of a height corrector. The methods and machines used for the conventionally machined part of the cylinder bore are broadly speaking very similar to those used for the slide valve. The finishing and superfinishing stages are more highly automated, however. Superfinishing is performed on specially designed and engineered Citroën lapping machines, which are fed by small manipulators. The principal of their operation is that of a multi-spindle drill, with between 16 and 32 diamond-charged tips arranged in a circle by increasing size. The tips go through the same hole, one after the other. Each tip removes a few microns at a time. Experience in the operation is nonetheless vital in order to monitor machine operation and control the quality of the finished product.

For the slide valve and the bore, just as for the hundreds of other types of parts manufactured at Asnières with the same meticulous attention, the guarantee for industrial micrometric finishing and production quality lies with the plant's Production Engineering department. This is where each stage and each operation is carefully analyzed in order to optimize existing systems, bur also to look for new ways of improving and defining new paths to progress. In short, this is where the technical power and potential of Asnières is focussed.

The example of the Production Engineering department at Asnières illustrates the main guidelines for industrial organization and Quality Assurance laid down in the Plan Mercure. These include zero defect, reduced stocks and manufacturing lead times, part traceability, machine capability follow-up and poka yoke (fool-proofing systems invented by the Japanese). These rules have been widely adopted since the plant was restructured into product lines.

A great deal of work is done on cutting tools, in conjunction with the suppliers. Indeed, there is a special "Cutting" section within the Production Engineering department. The section carefully studies and analyzes parameters as varied as cutting speed, depth of cut, part and tool attachment, grinding quality and tool life-cycles. The management of thousands of took is facilitated by a barcode identification system. By providing traceability, the system makes it easier to identify and manage all these parameters.

The Production Engineering department is the source of another example of methodological rigour: the spectrographic analyses carried out on the steel or aluminium bars delivered by suppliers. The raw material is checked and certified as conforming, right from reception, to specification in terms of quality as well as hardness or porosity (for aluminium). For each product line, a metrology laboratory attached to the Quality department is equipped with the advanced equipment needed for three-dimensional measurement.



Everything inside the lab is appraised and checked, from the standard for the superfinishing workshop to manufactured parts and tooling.
Automation is very much a part of the methods used. An average of FF7m per year is invested in the mechanization of machining operations. One after the other the existing workshops are being modernized and upgraded to keep in line with technological developments.

As for new manufacturing products or processes, in particular those implemented for the Xantia model (certain hydraulic components of which are unique), the automation drive has focussed primarily on assembly in an effort to cope with the growing demand for the latest model from Citroën!

THE PRINCIPLES
AND ADVANTAGES OF HYDRAULICS

Whether laden or empty, the height and trim of a hydraulically-suspended Citroën never budge an inch! These fundamental characteristics of the marque's famous suspension systems, all the components for which are manufactured in Asnières, blend ride-comfort (thanks to flexible suspension) and roadholding (with efficient shock-absorption). They also contribute significantly to safety. The principle of a hydraulic suspension system, properly termed a hydropneumatic suspension system, is simple. It basically operates by means of two fluids, a liquid (mineral oil) and a gas (in this case, nitrogen). Liquids and gases are respectively governed by two fundamental laws of physics:

- The first is an application of Pascal's theorem, whereby liquids at rest transfer any variation in pressure to which they are subjected to every point of their surface.
- The second is Boyle's law, which states that the product of the volume of a gas times its pressure is a constant at a fixed temperature (P x V = constant).

The compressibility of gas, which translates into a simple relationship between the volume filled by that gas and the pressure exerted on it, made it possible to design and build a high-pressure central pump and use a liquid as a means of transmitting the pressure output to the components in the system. Slaving other vehicle functions such as the braking, steering and clutch systems the hydraulic system to then becomes feasible. Control is effortless, making driving more comfortable, less tiring, and in the long run, safer.

State-of-the-art production technology

Increasing the quantity of pares produced requires an even greater level of quality in manufacturing. The new high-pressure pumps for the Xantia are a perfect illustration of how the Asnières plant took this factor into consideration and integrated micrometric know-how into state-of-the-art production technology. In order to fine-tune pressure production to the hydraulic functions of the vehicle, two new types of pumps were designed and engineered: one with 6 pistons for mechan ically-steered models (Dirmec) and for automatic control return motion (Diravi); and one with 6+2 pistons for models equipped with power steering (Ditass). The decision to manufacture the new pumps meant a completely new workshop had to be set up and fitted out with an impressive quantity of numerical control machines and robots as well as extremely high-precision machining plant. Numerical control delivers three advantages: flexibility, reduced machining times, and above all the ability to produce large quantities of parts which are absolutely identical. Furthermore, quality is enhanced throughout. At every stage, the precision of micrometric manufacturing is automatically controlled by a software program containing a database that can define the best tool for a given function as well as its optimum configuration for use.

But let there be no mistake. The human factor is the key to production quality in an ultra-automated workshop such as this, representing an investment of some FF220m. Here again, the skill of plant operators working closely in teams is vital. Experience and expertise at a micrometric level, even when transferred to a powerful industrial system, remain the same. The proof is that the men who are in charge of production have been hand-picked from the other workshops in the plant. Collectively, they have had more than 2,000 hours of training to familiarize them with the new technology !
Training is an ongoing concern at Asnières. Each year, each employee in the plant on average spends 39 hours in training, for the most part at the Citroën training institute in Saint-Ouen. The aims are in line with those laid down by the Plan Mercure: technical upgrading for greater responsibility and autonomy, decreased vertical hierarchy, group work with a suggestion incentive system, and so on. Involving the workforce is a decisive factor. The principal of self-inspection in manufacturing is just one facet of that requirement. The same attitude prevails in work meetings, such as quality circles and work groups within the Mercure module workshops, and in "production contracts", which workshop technicians manage themselves. The success of Asnières - and Citroën - in mastering large-scale micrometric production is a combination of all these factors.

Didier Counas

PROFILE OF ASNIÈRES

Start-up : 1949
Place : North-west suburb of Paris in the district of Asnières (Hauts-de-Seine).
Area : 78,000 m2 of land, with 65,000m2 of shop-floor.
Activity : manufacture of machined parts and hydraulic components.
Main workshops : free-cutting, machining, quenching and tempering, superfinishing, assembly and maintenance.
Daily output of hydraulic components : 14,000
Workforce (in 1993) : 660 (includes 500 operators, 130 technicians and 30 administrative staff), 850 in all with other departments.
Features : mass production and high-precision machining with micrometric tolerance compliance.

High precision machined parts			
	Tolerance compliance		
	Dimension out-of-surface	Shape	Finish
Male or female component	0.001 mm to 0.002 mm	0.0005 to 0.0001	0.0003 to 0.0008

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