PAPER Nr. : 27

MANUFACTURING CONTROL OVER THE REPRODUCTION OF HIGH INTEGRITY PARTS: A WAY TO IMPROVE THE SAFETY OF AERONAUTICAL PRODUCTS

BY

COSTANTINO BIGLIETTO — CESARE ARCARI

QUALITY DEPARTMENT
COSTRUZIONI AERONAUTICHE
GIOVANNI AGUSTA
ITALY

TENTH EUROPEAN ROTORCRAFT FORUM

AUGUST 28 – 31, 1984 — THE HAGUE, THE NETHERLANDS

A B S T R A C T

The Authors, on the basis of the thirty year experience logged by the Agusta Company in the production of helicopters have drafted this paper for the purpose of demonstrating that drawing requirements alone (tolerances, specifications, etc...) can not always guarantee full interchangeability for the parts.
The implications of this word which conventionally and from the dimensional viewpoint is synonymous with installabylity, is hereinafter reviewed in terms of serviceability, which in addition to the installability requirement also covers the equivalent fatigue life requirement.

1. Introduction

Any time a part is manufactured according to an approved drawing of a certified helicopter, we are talking about "reproduction" of that part.
In this paper we do not intend to go back to the certification phase of the design and/or to the first pre-production item, but we strictly deal with the related problems, after a set of approved drawings have been released and lot of raw material has to be transformed into gears, shafts, blades and whole helicopters.

2. General background

The Agusta Company, being Licensee with Bell Helicopter, Sikorsky Aircraft and Boeing Vertol for many years has been forced to develop its own knowledge and capability in the field of reproduction of parts, assemblies and end products.
Parts had to be reproduced according to the same set of drawings the Licensors, most of the time, used for their own production, and parts had to have similar mechanical integrity.
Apart from Agusta's experience during the reproduction of parts over the planned production years, different practical aspects must be considered by any helicopter manufacturer :

- Facilities improvements and/or relocations, involving manufacturing or assembly processes.

- Tooling improvements and/or modifications (casting models, dies for forgings, etc...).

- Different work sharing in the plant due to different work load conditions over the years.

- Subcontracting of parts, which is typical of fluctuating production rate, where the same part is manufactured partly in the plant and partly or totally by a subcontractor.

- Industrialization of the product, which is the great number of activities originated mainly by Industrial Engineering (example on structural assemblies) to improve productability.

- Changing of Supplier.

Each of the above mentioned events can have a big impact on the airworthiness and integrity of the part itself up to a point where it might show characteristics different from parts originally tested, even if they conform to drawing under all aspects.
A proper methodology must be developed and implemented in order to keep all possible parameters and relevant data under control such as manufacturing processes, inspection standards for acceptance, work sheets etc....

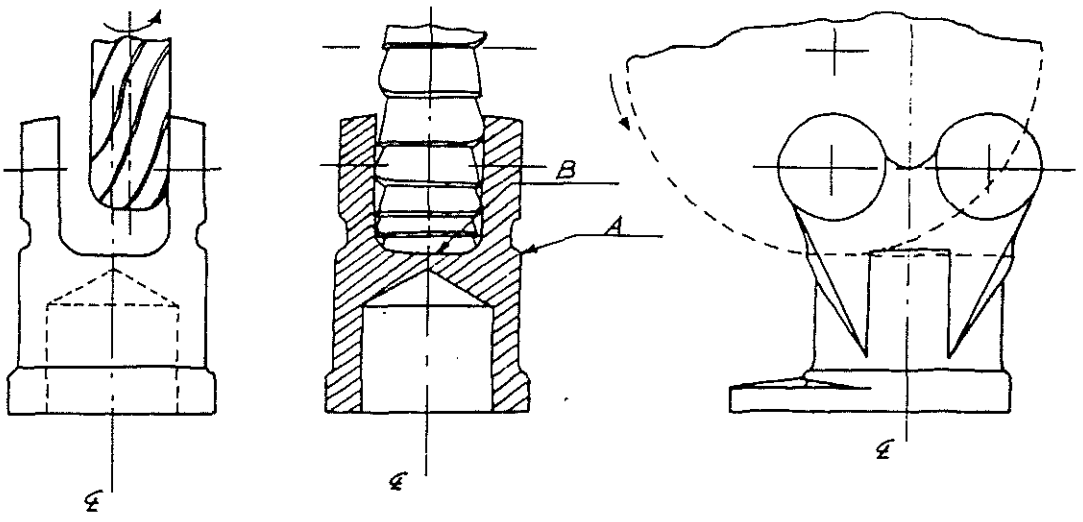
With the definition of "Manufacturing Control" we intend to identify the amount of activities developed by Quality Departement, by Manufacturing Engineering, Tooling Engineering, Purchasing in order to reproduce parts having characteristics essentially similar to those of the article originally manufactured and tested (i.e. the same fatigue life and mechanical integrity).
Helicopter manufacturers have developed different definitions and classifications of certain helicopter parts, such as critical parts, primary parts, process sensitive parts, etc..., but the basic concept adopted is rather the same: identify, among the total amount of parts normally one helicopter is made by, parts which are required to have a high level of integrity because of non redundancy and reliance on critical single load paths.
Parts such as the mast, main and tail rotor blades, parts located in the main and tail rotor hubs, in the main and tail gear boxes, and rotating controls are to be considered, in this paper, high integrity parts, whose mechanical integrity depends on safe fatigue life (some of which may be infinite).
On this parts, as we'll see later in this paper, particular attention has to be focused, when their reproduction takes place and proper manufacturing control has to be implemented.

3. History teaches

In this paragraph we are presenting several cases, taken from Agusta lived experience, where, sometimes too late, lack of consistent manufacturing control has resulted in premature failures, lot of troubles and, in the and, the loss of significative amount of money.
Each case is treated separately with its own reflections, considerations and conclusions on what kind of corrective actions have been deemed necessary.

CASE 1

Tail Rotor Hub



Description of the problem

The part has been manufactured in the plant for a long time without problems; then it was subcontracted to a subsidiary facility and, apparently no major defects has been found before acceptance phase of the first item.
Then during the survey was discovered a hardness level below minimun required in areas A and B (see sketch) even though the hardness test was not required.

Findings

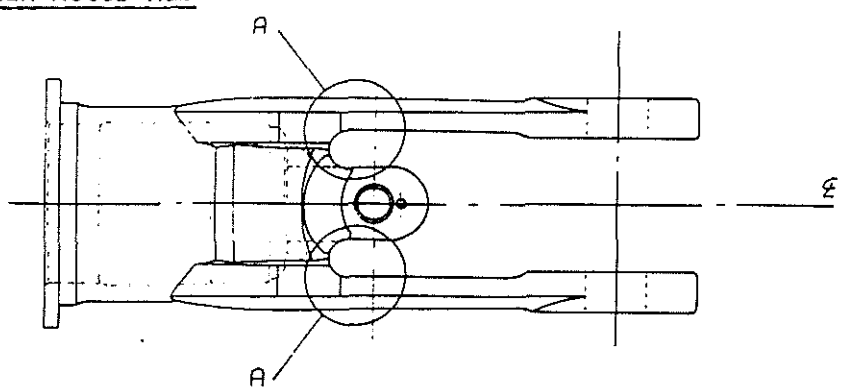
The subcontractor machined the slot by use of a heavy milling cutter, machining both sides and the bottom at one time, whereas, in Agusta's shops, that was obtained by employng a candle cutter and several cuts.
The excessive heat developed caused some of the forgings areas (2024 Al alloy) to be partially annealed.

Remarks

We believe that the check of the subcontractor's operations sheets against the Agusta manufacturing document would have prevented the problem.
In addition the drawing has been updated to include some hardness test requirements after the final machining.

CASE 2

Main Rotor Hub



Description of the problem

The part initially manufactured in the plant was sub-contracted to a subsidiary facility according to a general plan of work sharing.
During the acceptance phase of the first item performed by the chief inspector who originally accepted the parts in Agusta, was discovered a hardness level below the minimun requirements in areas A.

Findings

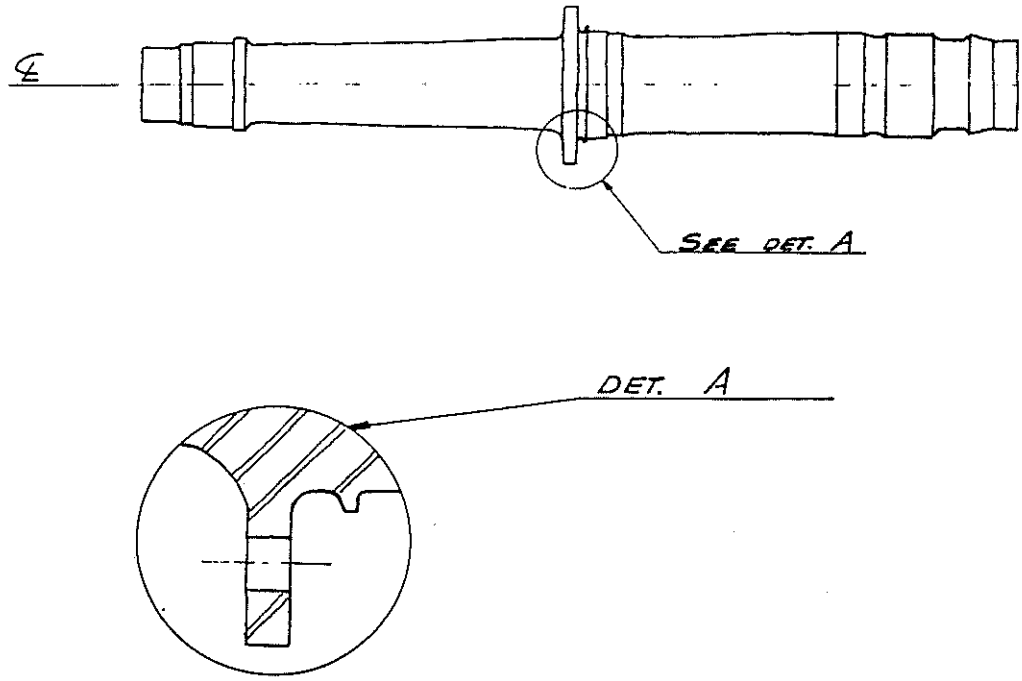
The subcontractor machined the slots by heavy milling operations and the excessive heat developed caused some spots to partially anneal.

Remarks

We believe that the check of the subcontractor's operation sheets against the Agusta original manufacturing data would have prevented the problem, because the sensitivity of that area had been previously experienced by Agusta.
In addition the drawing have been updated to include some specific hardness checks after machining.

CASE 3

Main Rotor Shaft



Description of the problem

When the first lot of masts had been reproduced by a different source, they failed to recognize some hardened spots, mainly in the flange radius relief zone (see detail A of the sketch).
The defects had been found by Agusta Receiving inspection, which requested some additional nital etching checks.

Findings

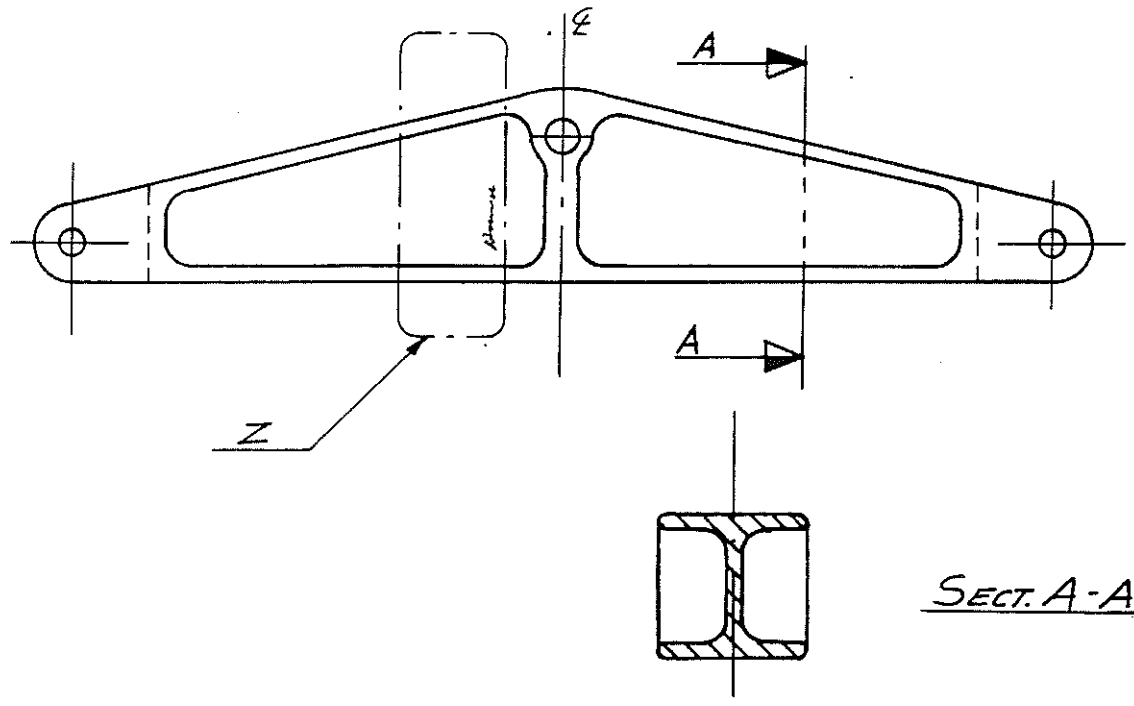
In house experience in manufacturing the shaft suggested in the past some additional inspection requirements, besides those of the drawing, which have been included in Agusta's work and inspection sheets.
One of those requirements calls for a nital etching check after machining (not grinding) of the relief, because due to the high strenght of the material (44-48 Rc - 126-146 Kg/mm^2) subjected to very high frequency vibrations causing the contacting material to harden had been induced by the special slender tool.

Remarks

Even though defective parts have not been put in service, timely manufacturing control would have prevented scraps. In this case the drawings have not been changed to include those additional requirements, considering them as pre-requisite of working and inspection sheets.

CASE 4

Stabilizer Bar Assembly
(already known as "the killing signature case")



Description of the problem

Early cracks had been found in Z area starting from the very thin web of the double T section.
The helicopter was in pre-production phase but several ships had, at the time, already flown and logged several hours, without problems reported on the stabilizer bar.
Several parts had to be removed from flight.

Findings

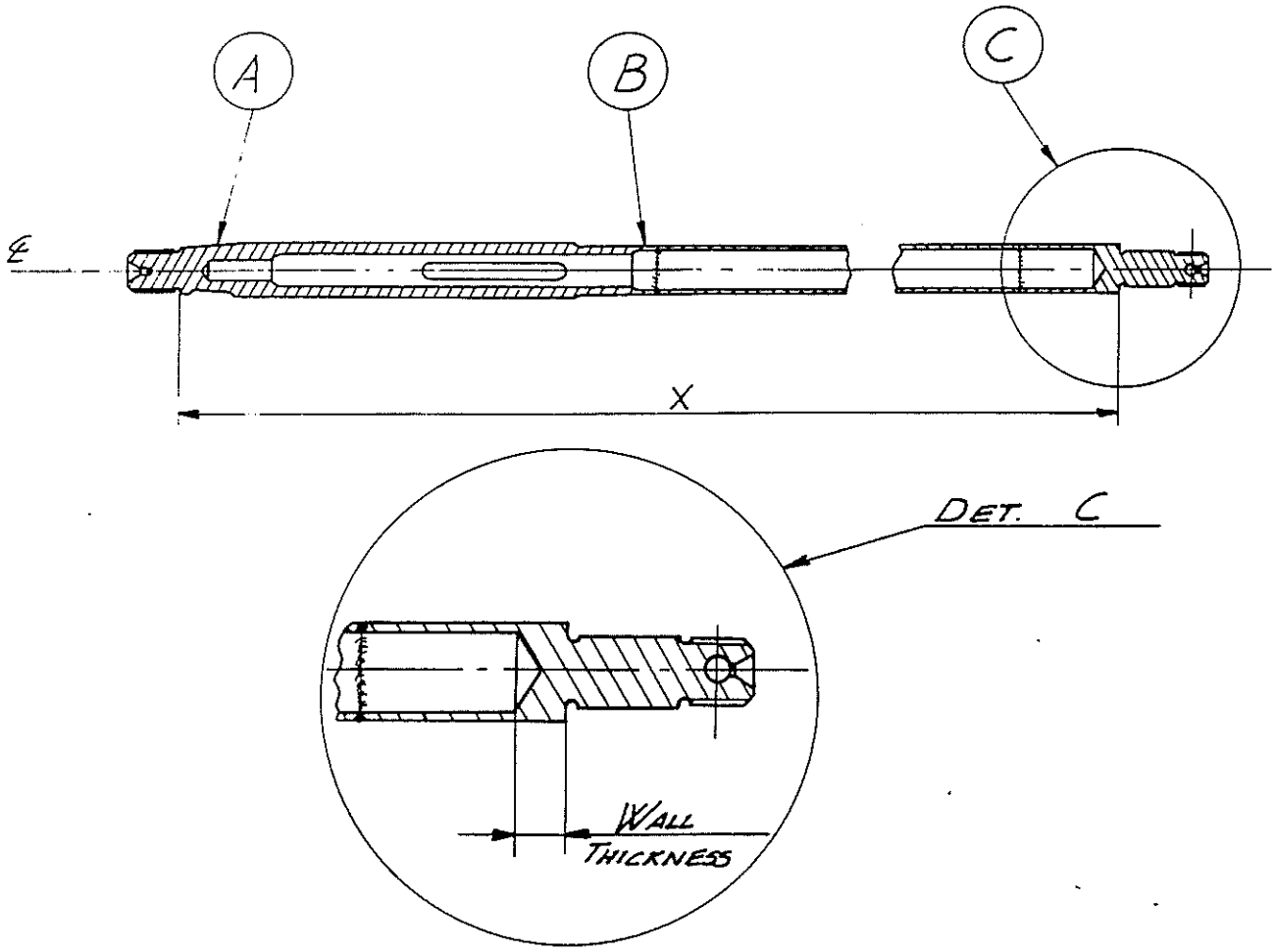
The investigation revealed the cracks started from a vibro- etched signature by the inspector who made the final acceptance of the part.
Previous acceptance had been made in a different shop of the factory which manufactured the first pre-production articles and then transfered to a successive production shop for the series production.
The transfer had been made without checking of the marking process, previously done by rubber stamp.

Remarks

It has been found, that also the drawing was defective about the marking, not indicating precisely how and where to mark.
Later it has been updated.

CASE 5

Tail Rotor Control Pitch Rod



Description

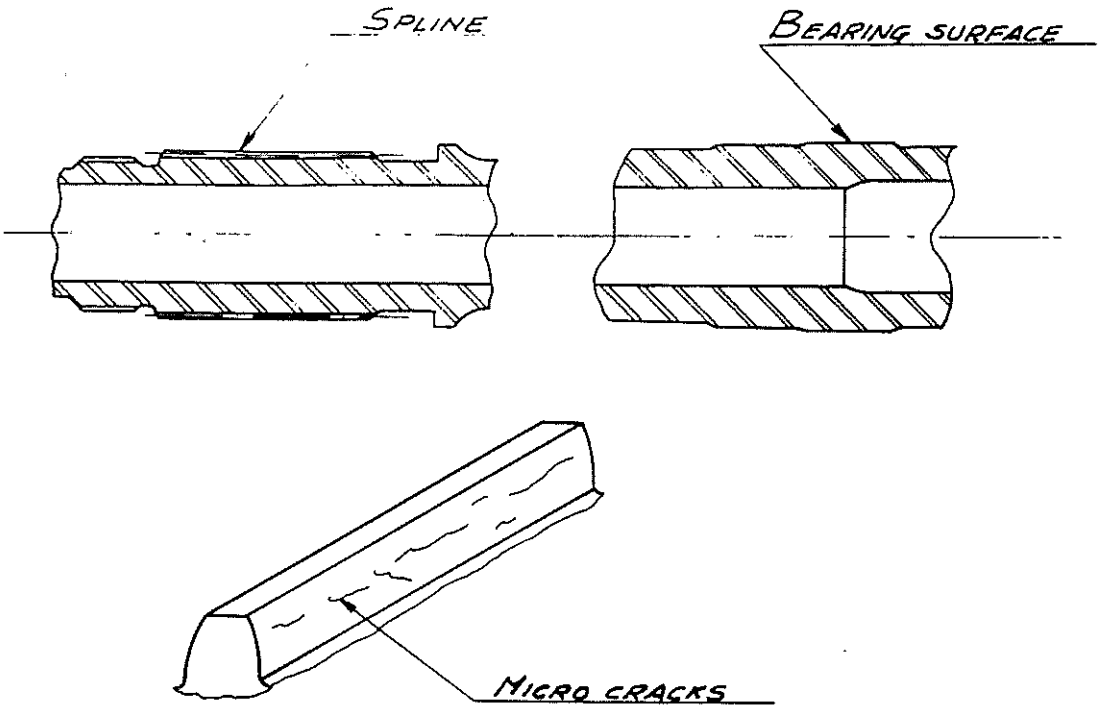
The pitch rod, according to licensee drawing requirements is made by three different parts, namely A, B, C, machined separately to their dimension and then flash welded together. After welding, the final dimension X has to be machined according to B/P dimensions.
In this case Agusta did a positive manufacturing control, because with the first part produced has been evaluated the minimun wall thickness risk (part C being a hollow part) .and and additional X ray inspection had been introduced on the Operation Sheets to monitor the real wall thickness on the finished part.
The manufacturing process so developed, has been ever since adopted in the production history of the part, during the years, and it is still in use.

Remarks

The Licensee issued, in the past, an airworthiness service bulletin requiring X ray inspection to the pitch control rods manufactured by him for the minimun wall thickness problem. The bulletin was not applicable to Agusta production.

CASE 6

Tail Rotor Shaft Spline



Description of the problem

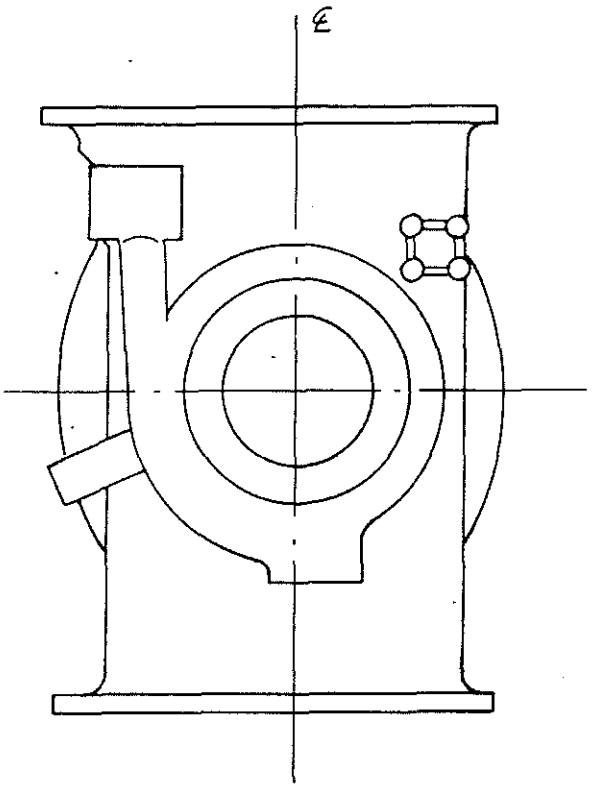
The problem appeared evident even from the first time we reproduced the part: after the nitriding treatment according to specs., the parts were ground and then magnetic inspected.
Surface micro-cracks became apparent only on spline teeth, not on the bearing area, causing the rejection and scrapping of the parts, which happened several times.
Even with the Licensee support, it took time and efforts to clearly identify the correct temperatures and NH3 dissociation required for the first and second phase of the nitriding process. In addition, in order to better control the in process development, a spline sector sample ha been introduced, instead of the cylindrical sample, to check the microstructure on close to real part condition.
The magnaflux check has been introduced before and after grinding.

Remarks

It goes without saying, that when this part will be reproduced by other source, the transfering of all the above significant manufacturing and inspection data is a "must" in order to receive back to Agusta a part with the same integrity level of that we are producing now.
Doing so we will perform the manufacturing control over it.

CASE 7

Acceptance Criteria



Description of the problem

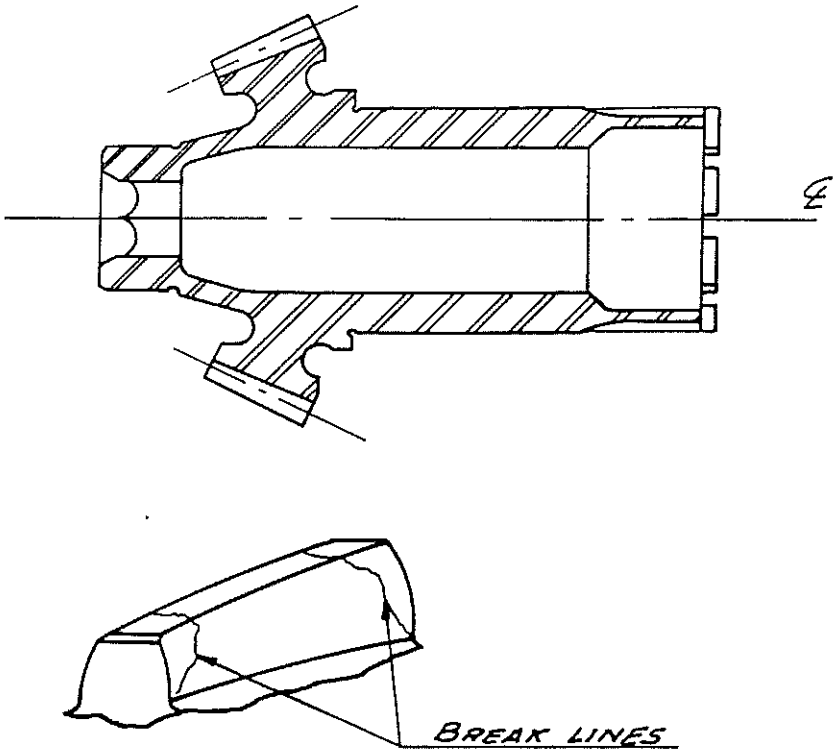
When a new Agusta subsidiary Plant for producing castings, was opened, in the south of Italy, we experienced a noticeable great amount of scraps and rejections.
A deeper analysis revealed, among other aspects, that castings accepted by subsidiary Q.C., were rejected by Agusta inspectors.
We had to transfer to them, in addition to the models already available, all the X ray inspection data for each P/N produced (current intensity, voltage, position) the same standard for acceptance we adopted in the past on our production, specifying the extent and location of permissible flows.

Remarks

Today, we believe, from the quality stand point, that the method adopted is the only way to save the integrity of the parts and to avoid loss of money.

CASE 8

Gear



Description of the problem

The defect was very singular; one lot of gears already machined, finished and waiting for final acceptance broke by themselves, on few teeth, generating cracks as shown by the sketch above.

Findings

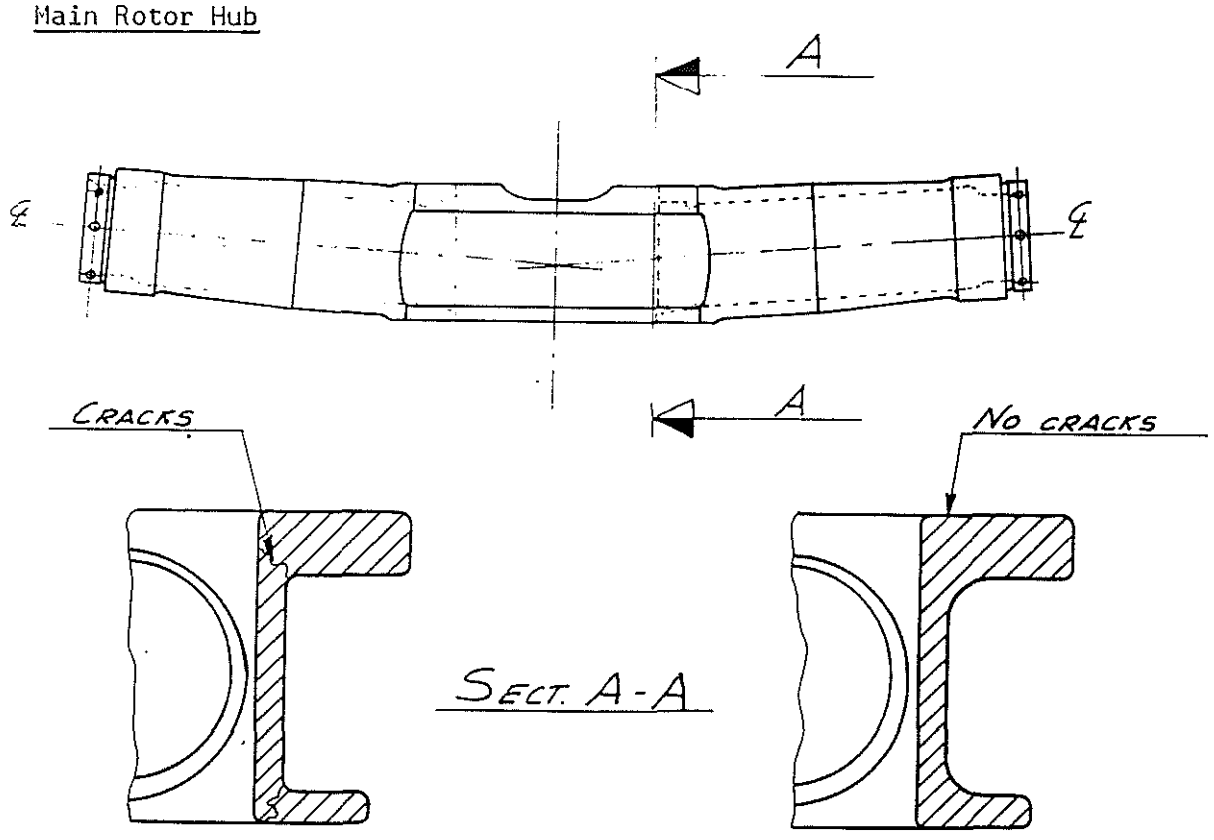
The heat treating process was performed according to the specifications called out by the relevant drawing, but it has been discovered that the time elapsed from the deep freeze phase and the stress relief phase on that lot, was several days long, due to internal material flow which was recently changed. The reason of the cracks was the very high internal stress condition, after the deep freeze, not suddenly removed by the thermal relief as done previously.
The operation sheet has been modified, specifying the tempering within a few hours after deep freezing, which was, not written before.

Remarks

In gears manufacturing we learnt that the detailed manufacturing process must be closely followed in order to reproduce parts, in different lots, with the same characteristics.

CASE 9

Main Rotor Hub



Description of the problem

A high rate of scraps, due to heavy cracks, as shown, after heat treatment process in a semi-finished condition. The part being subcontracted to an Agusta supplier.

Findings

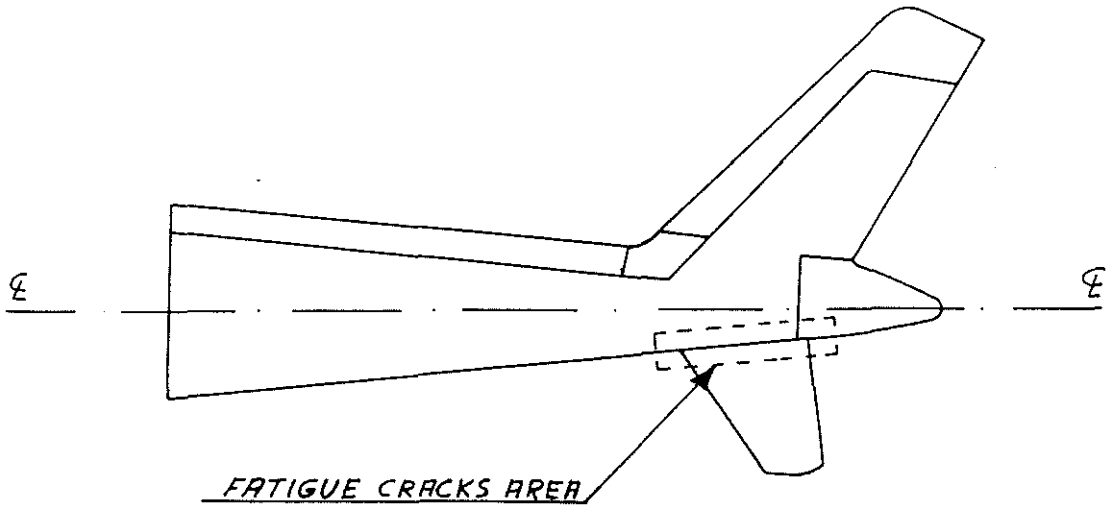
The investigation revealed that the subcontractor heat-treatment configuration was different from that adopted by Agusta in the previous years when the hub was manufactured in the Cascina Costa plant. The fault configuration showed too small radius between the web and the flanges.
The heat treatment shape, already experienced by Agusta and more suitable to prevent internal stresses, solved the problem;

Remarks

Similarly to the same previous cases shown, we believe that the check of subcontractor operation sheets against the Agusta manufacturing documents, would have prevented the scraps and the working hours lost.

CASE 10

Tail Boom Assy

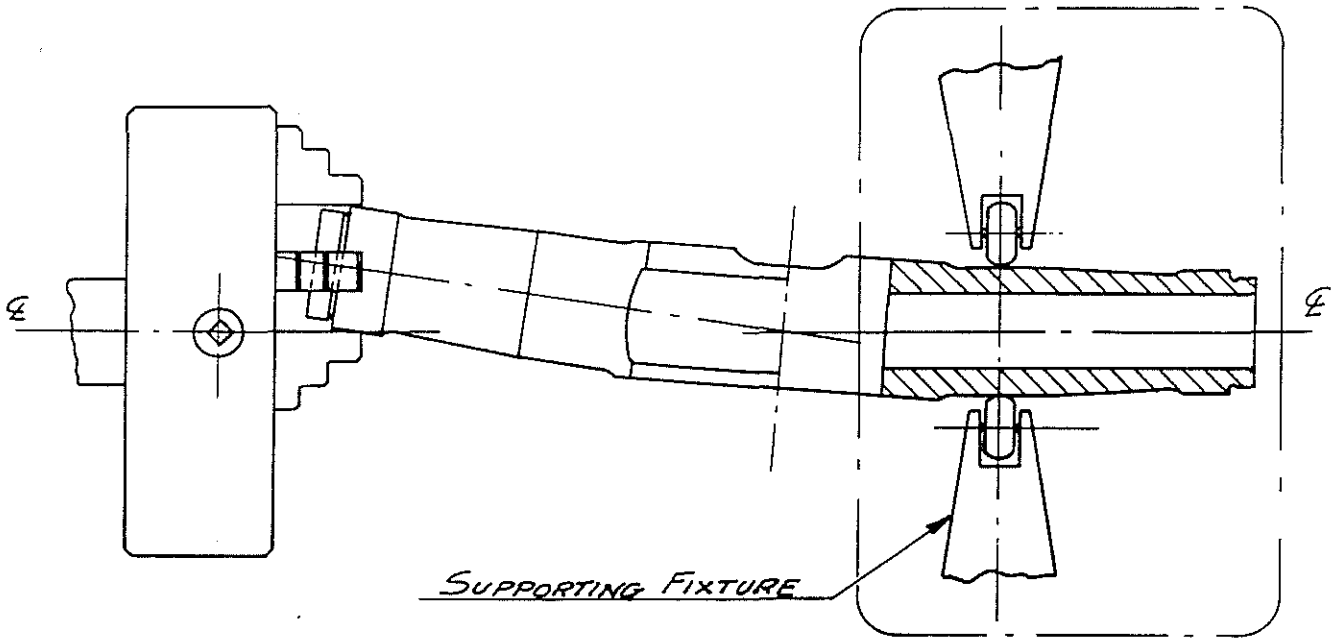


Description

The assembly was pre-produced with simple assembly jigs and by highly specialized operators.
One of those articles underwent a static and fatigue testing positively.
Then massive production started, with a new series of tools and assembly jigs.
Later in service the helicopter experienced fatigue cracks originating in the joint area between the fin and the assembly sequence.
The industrialization did not properly replace the care adopted on the test articles, and suitable changes to the tool-chain and to the assembly sequence were made.
The case tought us to transfer to production articles as much as possible the assembly principles adopted on test items.

CASE 11

Arms of Main Rotor Hub

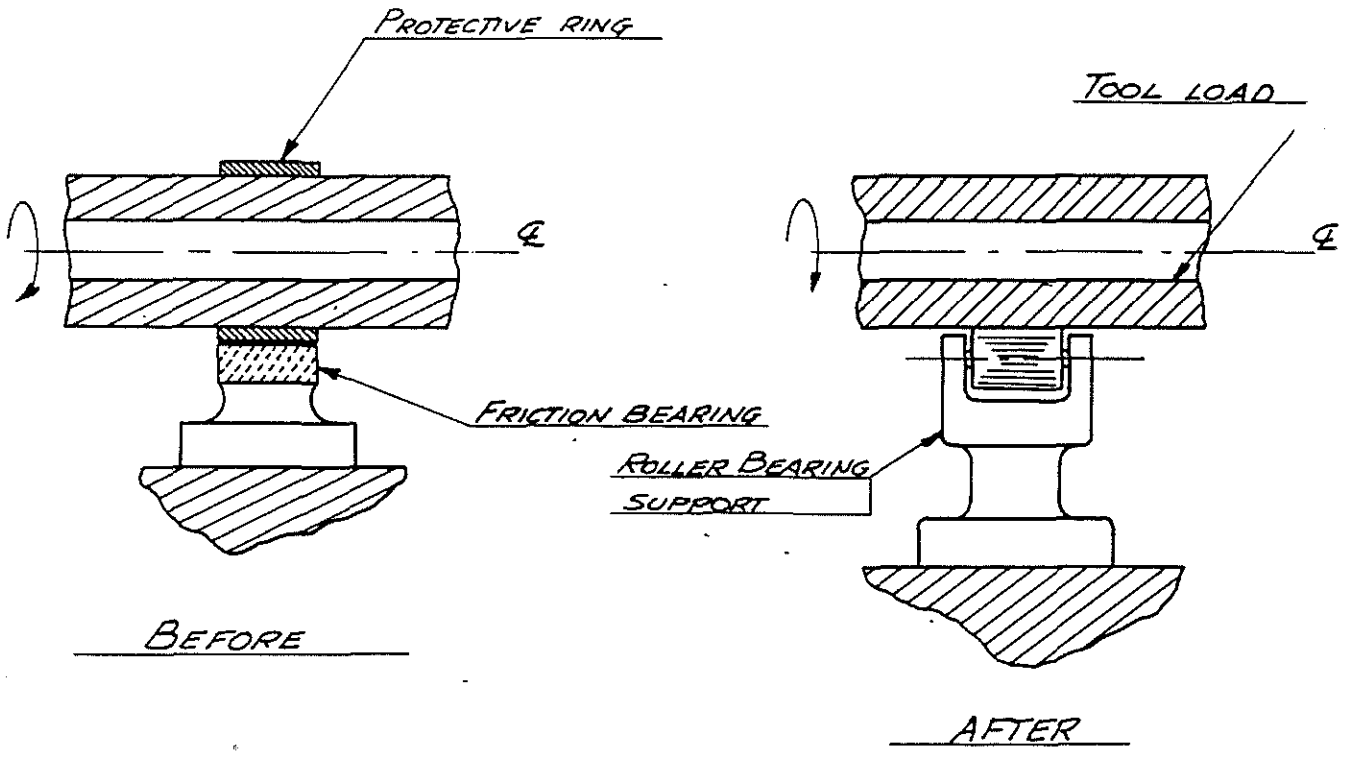


Description of the problem

The shot peening operation performed according to the blue print requirements, showed a strange difference in brightness on the external surface of the hollow arm and it was tape masked along the circumferences.
Such area was later discovered being over hardened and not acceptable.

Findings

The part had been totally manufactured in plant for many years, so there was no guilty subcontractor to find out.
The investigation revealed a different fixture adopted for internal boring of the hollow arm.



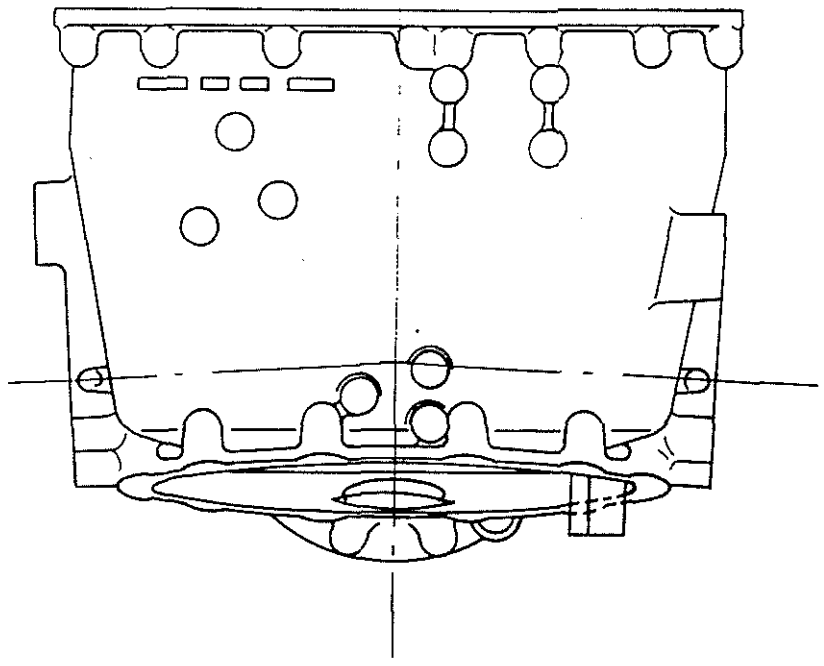
The new roller bearing support, adopted without protective ring, to permit higher cutting speed over hardened the external surface due to tool load.

Remarks

This case tought us that, even minimun changes to a manufacturing process must be evaluated, before approval, against the integrity of the resulting parts.
If doubts exist, let's try before with tests on samples.

CASE 12

Main Gear Box Housing



Description of the problem

The trouble was very singular and it took a lot of time to find out the solution.
During the production test-run of a brand new main gear box, we experienced excessive lubricating oil temperature.
The next tests gave the same results and the production was practically stopped.

Investigation

The people involved to solve the problem, literally squeeze out their brains scratching their heads between one disassembly of the gear box and the other. At last they found defective circulation of lubricating oil due to difference of internal configuration of the housing casting.

Remarks

It was a reproduction problem, because it happened the casting was the first item of a series produced by a new supplier. Agusta could'nt blame the vendor because it was found-out that the differences were within the drawing requirements.
As usual we learn by error, and we introduced a specific configuration check sheet on high integrity casting in order to record the section shape of casting of the first item produced and to have it complied with any time the same part is produced by a new supplier.

4. Final Consideration

The cases presented before, among the many other we experienced are taken from the real life of an helicopter manufacturer and have been chosen in order to relay to the audience the same lessons we logged in many years in the field of reproduction parts.
The drawing has to be as much as possible accurate as far as the manufacturing aspects are concerned (marking, relief radius, minimum wall thickness indications, etc...) and must identify, when the part is a "high integrity " one.
However, the drawing alone is not sufficient to permit the reproduction of parts having same characteristics as those for which the certification of the drawing itself was granted.
The facts presented, explain by themselves that the manufacturing process, the operation sheet, the acceptance standard, the tooling and the operator himself, contribute concurr all together to the integrity of the final product.
We do not know any magic formula to introduce the concepts other than to seed and make them grow up inside the conscience of each professional engineer of the Manufacturing Engineering Dpt., Industrial Engineering, Tooling Engineering Dpt., Quality Control Dpt. and Purchasing Dpt.
In other words the manufacturing control is made up by all the departements involved in reproducing high integrity parts; the task of the Quality people is to survey and to monitor that the entire process is done correctly and according to procedures previously planned.
A good and sound manufacturing control means, for a manufacturer, more safe helicopters.

5. Conclusions

As shown by the previous examples, the close compliance with drawing requirements (dimensions, specs., etc...) in some cases, is not sufficient to assure the interchangeability of some helicopter parts.
This is because the term interchangeability has a broader meaning compared to the meaning so far associated to with it and which is the basis itself of the industrial world.
For certain parts interchangeability means suitability to behave, along the use, in a similar way (example same fatigue life).
The concept, originally born as static, is getting today more and more dynamic.
As matter of fact, it is extremely difficult to have their concept totally reflected by drawing data such as the dimensions tolerance, for example, and today, the succesful completion of a reproduction is mainly committed to the background and sensitivity of the manufacturer.
We wish, however, to point out some recommendations:

- The manufacturing operation sheet must be closely monitored during its history in order to evaluate the impact of evenly apparent minor changes to the document which originated parts firstly tested. The same requirements is applicable to subcontractors.

- The manufacturer has to be considered the only approved source for vital parts; alternative sources must be cleared by the manufacturer only.

The Airworthiness Authorities, as far as we know, are becoming more detailed in establishing regulations and criteria concerning the minimun requirements of the manufacturing control of high integrity parts.
The British Civil Airworthiness Requirements - Working Draft of Chapter G4-9 is one remarkable example.

- o -

The authors wish to thank:

Mr. Luigi Colombo	Mech. Shop Chief Inspector
Mr. Salvatore Bertolami	Heat Treat e Carb.Chief Insp.
Mr. Gianni Quadrelli	Quality Labs
Mr. Alfonso Gaudino	Q.ty Dpt Elicotteri Merid.
Mr. Pietro Aldeni	Sheet Metal Shop Chief Insp.

who greatly contributed to this paper and who have been the fore-runner of manufacturing control activities at the Agusta Company.

- o -