“On Line Measuring in PM complex Parts by Conoscopic Holography”

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Abstract

The rapidly evolution in the concept of verification and measuring methods toward the features for serial parts, as well as the increasing demand for tighter geometrical tolerances and shape defects, has addressed Sinterstahl Asturias, in co-operation with Korvus Tecnología y Desarrollo and Oviedo University, to develop a measuring method and system that meets the new requirements.

A novel automatic on-line measuring device based on a non-contact measurement technology called conoscopic holography is shown in the paper. This non-contact method allows on line measuring of complex sintered parts in a precise, fast, robust, flexible and economic way.

Obtained data are used to define the external contours, maximum and minimum of a particular feature shape defects, tooth profile among other things.

Furthermore the database can be used for analysing in depth metrological aspects under the statistical tolerancing point of view, in order to deal with the intrinsic non-normality and their effects.

Introduction

Accurate measurement of complex sintered pieces is a slow process, requiring costly installations and equipments, and trained personnel. In on-line production, this leads to quality control and process feedback solutions where only a small set of pieces are fully inspected (with a high delay), and the major part being only tested by go/no go calipers gauges that can only assess the extreme values of some dimensions.

In the industry of sintered automobile synchronizer hubs, as in many others, a fast on-line measurement system for the 100% of the production is a very important tool for production and quality control, enabling:

- Extended quality control of the 100% of the production.
- Shorter start-up times.
- Improved knowledge of the process and influence of the parameters.
- Database management of the information.

A measurement system has been developed with the aim to achieve 100 % production quality control of several dimensional parameters in a factory of synchronizer hubs for the automobile industry. See Fig. 1 at next page.

The requirements for the measurement system are:

- Measurement of 3 diameters (head, foot and guide) at 3 different heights, for the full range of the production.
- Automatic checks of the dimensions, comparison with nominal values and their tolerances, and database storage.
- 10 pieces per minute throughput, with automatic load, unload, and separation of the defective pieces.
- Absolute accuracy, better than 10 µm in diameters; repeatability better than 4 µm.
- Fast and easy adaptation to all the production ranges.
- Standard software with different levels of privileges according to the user level. Easy interface for low level user full access for high level user.

Features in the synchro hubs manufacturing

The synchroniser hub is probably one of the complex PM part that has had a faster growth during the last decade.

As the gear box manufactures were realising about the advantages of this manufacturing method as well as about its possibilities beyond the classic machined parts, they were asking for more accurate geometrical tolerancing of form. [1]

Sinterstahl is developing methods to meet the customer needs and to lead the technological vanguard about some families of products considered in its CoE's (Centre of Excellence). Within this strategy, Sinterstahl orientates the process to manage the shape of the hubs in the early manufacturing stages prior than correct it at the end.

Features that were considered in the past, according to the classic machining standards, "shape defects" become a competitive advantage once the customer discover that this shapes can be controlled and functionally reoriented.

But classic measuring methods such CMM are not fast enough and need specialised measuring operators. According to the modern concept, the personnel has to be focused in producing high quality parts and offer the best service level to the customers. For this aim, verification methods and devices able to provide accurate and on line information are crucial.

Many systems were tested before the fruitfully collaboration between Sinterstahl Asturias S.A., Korvus Tecnología y Desarrollo and the Oviedo University , has offered as a result the application of the holography to the PM complex parts and in particular to the high volumes synchro hubs manufacturing.

Conoscopic holography

As the novel measurement technology used “Conoscopic Holography” is not broadly known, a brief explanation follows. Conoscopic holography (referred to as CH in the following) was developed by Prof. Gabriel Sirat and Prof. Demetri Psaltis at the California Institute of Technology [2] , [3]. The Israeli Company Optimet owns the exclusive rights for this technology, protected by several patents.

CH is a form of incoherent light interferometry, based on the interference that occurs between ordinary and extraordinary rays into which polarized monochromatic light is divided when crossing a uniaxial crystal. When the light emitted or reflected by a source point is passed through the crystal, the interference figure is a Gabor Zone Lens that can be captured by a standard CCD camera. Once the interferogram has been processed, the distance of the light emitting point can be obtained. The Fig.1 shows the scheme of the conoscope. The light for illuminating the point is provided by a laser source installed inside the sensor.

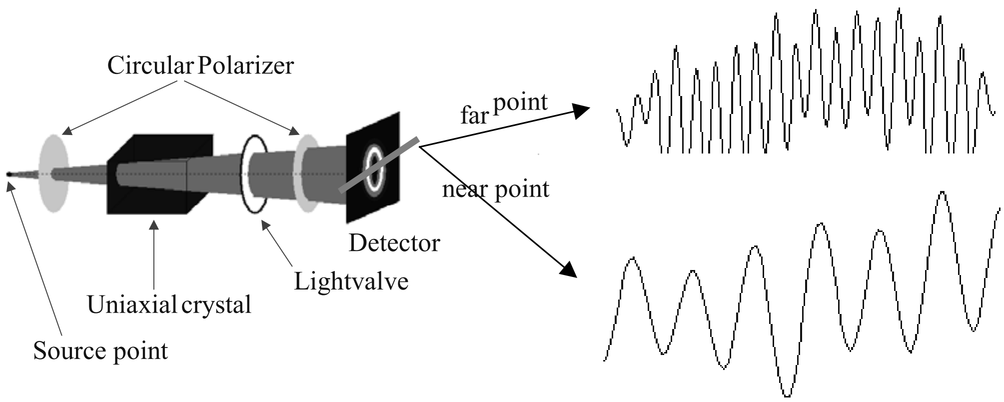

Fig. 1- *Conoscope scheme*

This technique has many advantages over its competitors: it is completely collinear and very accurate; the range of measurement can be easily changed (by simply exchanging lenses); it can measure surfaces with a slope of nearly 90º; it can be extended for direct 2-D measurement (profilometry), or even to 3-D.

For this case, a punctual measurement device called Conoprobe, shown in Fig. 2, has been used, giving up to 850 measured points per second with a precision better than 3 μm.

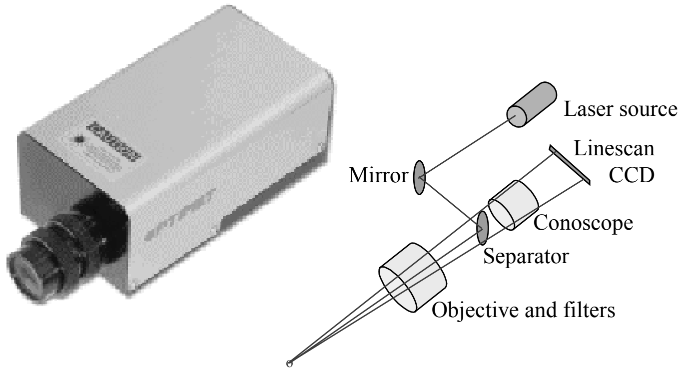

Fig. 2 - *Conoprobe sensor*

System setup

The developed measurement system is based in Optimet's Conoprobe [1], placed on a structure where a stage provides translation and rotation to the hubs; this roto-translation combined with the measurements of the Conoprobe give the raw measurements, and the appropriate software processes the raw data to give the desired diameter values. Fig. 3.

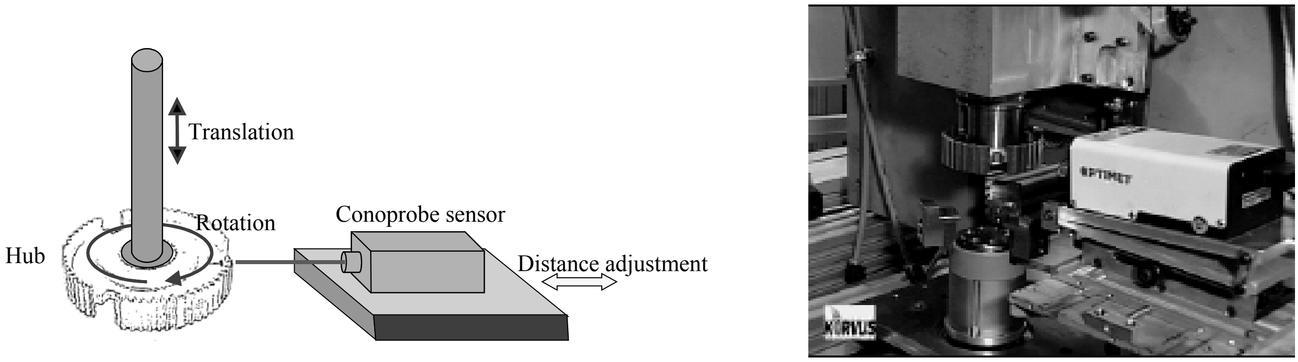

Fig. 3 - *Measuring system*

The measurement system is divided in two independent structures, the load/unload cell and the measurement column The load/unload system permits to feed pieces to the column, being able to work with 3 hubs at the same time: one loading, other measuring, a 3rd unloading. This allows achieving a high operation rate of 1 hub each 7 seconds with measurements at 3 heights, 1 second more per additional height.

The system operates in a completely automatic way. When a new piece arrives, it is detected and loaded to the system. The measurement column takes the hub, places it at the desired height, and rotates it at 1 rps, while the Conoprobe starts measuring. Once all the desired heights are scanned, the measurement column releases the hub and it is unloaded, while another one has been prepared by the load/unload cell and is immediately loaded.

When one measurement is finished, the raw data are processed, and the desired diameter values are obtained. These values are compared with a database of nominal parameters, enabling to automatically decide if the piece is valid or not, and to have objective real time production data for immediate feedback of the production line or for further statistical analysis. Fig 4

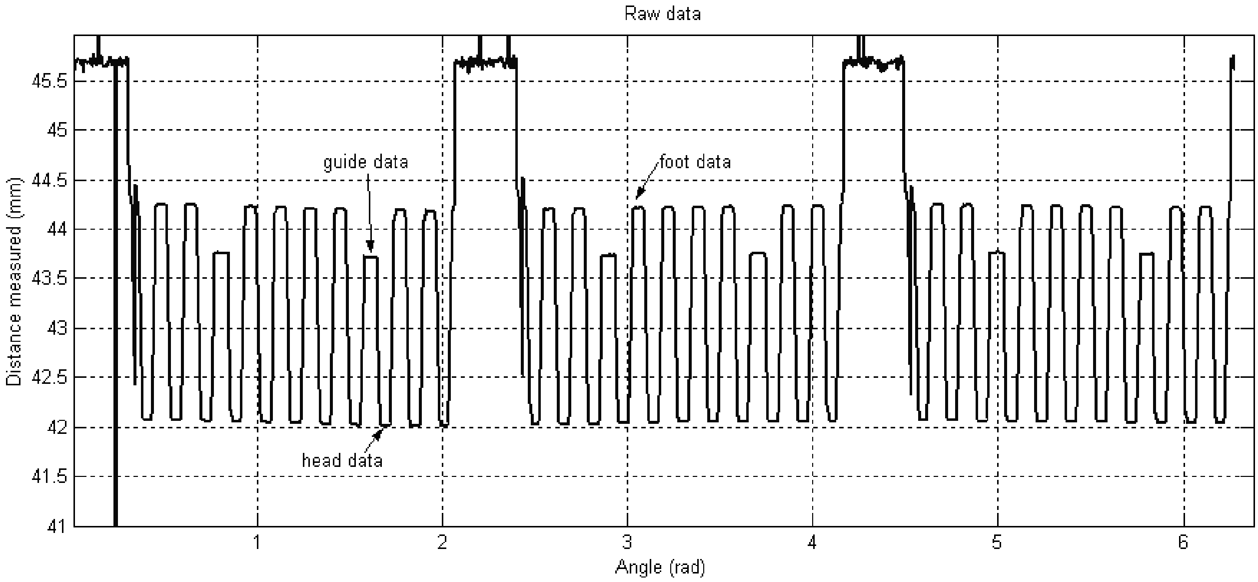

Fig. 4 - *Raw data*

Results

The results of the system have been very useful for the production and quality control. Currently, the system processes and stores diameter data of the head, foot and guide (if present) of the hub, at the various heights decided by the operator.

Ten parts from different populations, made in different production series, were measured nine times each one. The Fig. 5 shows the mean head diameters of each part at different measuring moments. The figure shows, like an example, the fluctuation in measure for one part, maximum fluctuation is within 0.004 mm.

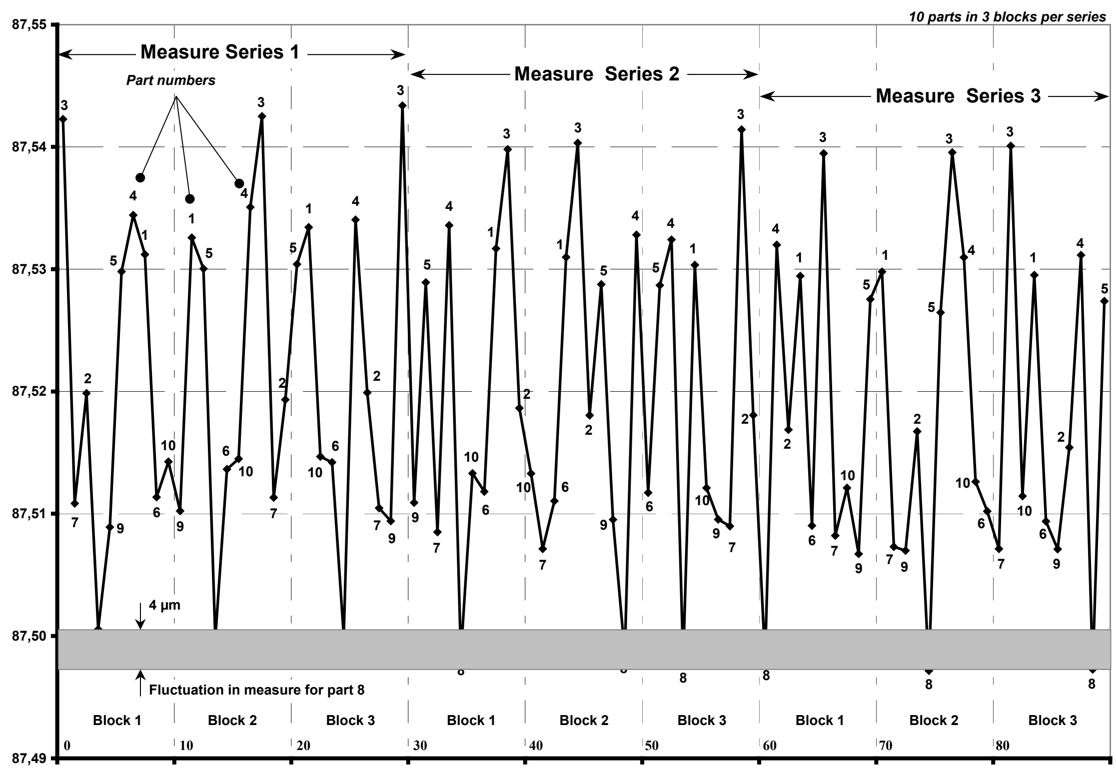

Fig. 5 – *Head diameters*

The Fig. 6 shows the results of a repeatability and reproducibility study for head diameter in previous 10 parts passing all the process of load / measurement / unload. Final result shows that absolute value for R&R index (ISO 5725-2:1994) is 0.009 mm [5], that is to say, a percentage error relative to measuring system of 2.2% regarding to the tolerance interval for this part dimension.

R&R STUDY	PART										AVERAGE	
	1	2	3	4	5	6	7	8	9	10		
1. A 1	87,531	87,520	87,542	87,534	87,530	87,511	87,511	87,501	87,509	87,514		
2. 2	87,533	87,519	87,543	87,535	87,530	87,514	87,511	87,500	87,510	87,514		
3. 3	87,533	87,520	87,543	87,534	87,530	87,514	87,510	87,500	87,509	87,515		
4. Average	87,532	87,520	87,543	87,535	87,530	87,513	87,511	87,500	87,510	87,514	$\overline{X}_a$=	**87,5207**
5. Range	0,002	0,001	0,001	0,001	0,001	0,003	0,001	0,001	0,001	0,000	$\overline{R}_a$=	**0,0012**
6. B 1	87,532	87,519	87,540	87,534	87,529	87,512	87,509	87,498	87,511	87,513		
7. 2	87,531	87,518	87,540	87,533	87,529	87,511	87,507	87,499	87,510	87,513		
8. 3	87,530	87,518	87,541	87,532	87,529	87,512	87,509	87,498	87,510	87,512		
9. Average	87,531	87,518	87,541	87,533	87,529	87,512	87,508	87,498	87,510	87,513	$\overline{X}_b$=	**87,5192**
10. Range	0,001	0,001	0,002	0,001	0,000	0,001	0,002	0,001	0,001	0,001	$\overline{R}_b$=	**0,001083145**
11. C 1	87,529	87,517	87,539	87,532	87,528	87,509	87,508	87,498	87,507	87,512		
12. 2	87,530	87,517	87,540	87,531	87,526	87,510	87,507	87,497	87,507	87,513		
13. 3	87,530	87,515	87,540	87,531	87,527	87,509	87,507	87,497	87,507	87,511		
14. Average	87,530	87,516	87,540	87,531	87,527	87,510	87,508	87,498	87,507	87,512	$\overline{X}_c$=	**87,5178**
15. Range	0,000	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,000	0,001	$\overline{R}_c$=	**0,0009**
16. Total average ($\overline{X}p$)	**87,531**	**87,518**	**87,541**	**87,533**	**87,529**	**87,511**	**87,509**	**87,499**	**87,509**	**87,513**	$\overline{\overline{X}}$ =	**87,5192**
											R_p=	**0,0423**
17.	Number of series:					3					$\overline{R}$ =	**0,0011**
18.	Value of Xdiff										X_{diff}=	**0,003**
19.	Calculation UCL_R				D_4=	2,58					UCL_R	**0,0027**
20.	Calculation LCL_R				D_3=	0					LCL_R **0**	

Measuring equipment analysis:	**% of tolerance (TOL)**
Repeatability - Equipment variation (EV)	%EV = 100(EV/TV)
EV = $\overline{\overline{R}}$ x K_1 $\overline{\overline{R}}$ 0,001	**%EV** = **0,81** %
K_1 3,05	
EV 0,003	
Number of series / **K_1**: 2 → 4,56; 3 → 3,05	
Reproducibility - Environment variations (AV)	%AV = 100(AV/TV)
AV = 0,008005 0,000	**%AV** = **2,00** %
K_2 2,7	
r = 3	
n= 10	
nr = 30	
Number of series 2 3	n = nº de piezas
K_2 3,65 2,7	r = nº de ensayos
Repeatability & Reproducibility (R&R)	% R&R = 100(R&R/TV)
R&R = $\sqrt{EV^2+AV^2}$	**% R&R** = **2,16** %
R&R = 0,008637	

Fig. 6 – *Head diameters*

The system can be easy adapted to different measurements. A 20 heights measurement is done, giving invaluable information about the full shape of the hub. The Fig. 7 shows the results of a shape of the guide diameter.

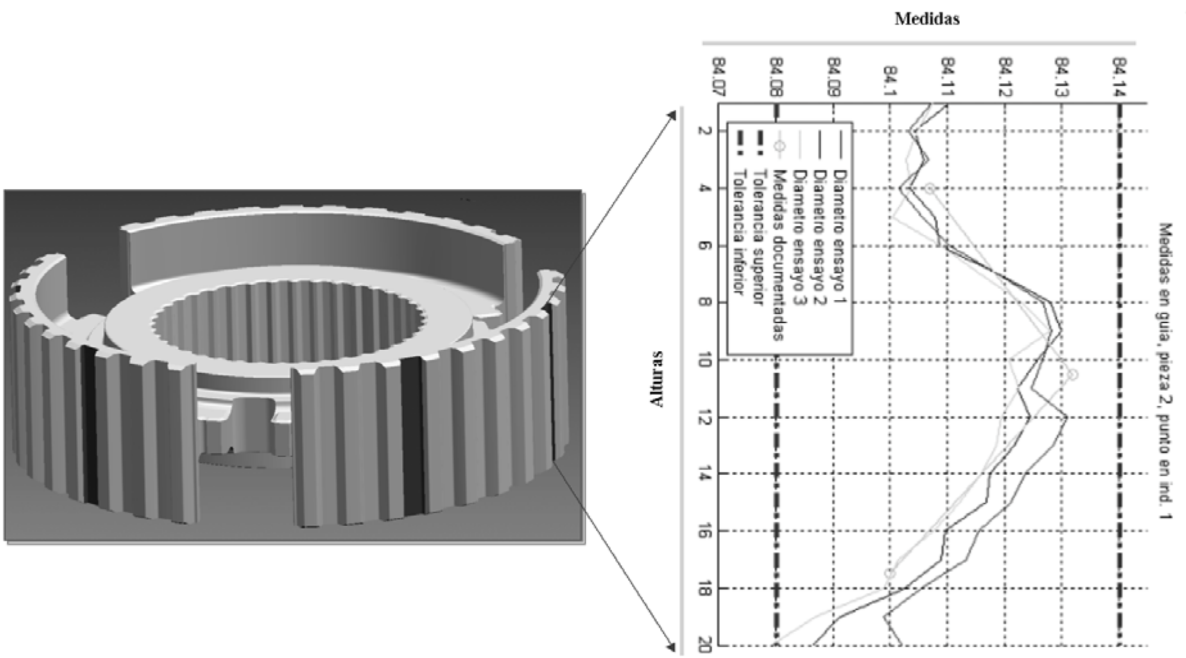

Fig. 7 – *Guide diameter, 20 heights*

Conclusions

A system for on-line quality control of the production has been developed and installed in the synchronizer hub plant of Sinterstahl Asturias S.A. The system will become a very important tool for increasing the competitiveness of the plant and the customers satisfaction.

The system is fast, accurate, automatic, and can work on-line as well as off-line. It actually gives important parameters of the product. R&R studies have shown that the system meets the specification and has been validated according to the very strict procedures of Sinterstahl Asturias S.A.

Upgrades are previewed for increasing the number of measurements taken: using the raw data and absolute control of the positioning system, it becomes easy to calculate other variables or perform other measurements:

- Calculate others parameter related to revolution features such as primitive diameter
- Measure groove width and position.
- Obtain the tooth profile.
- Attributive analyses.

By simple modifications such as implementing a translation device and a second sensor provided with a periscope, is possible to extend the measuring to the upper and lower levels and to the inner teeth. This will allow measuring steps between the hub and the teeth, deburring control and edge shape, radial and axial oscillations and the main characteristics of the inner teeth.

An important technological breakthrough has been started in this project regarding on-line dimensional quality control. Cylindrical measurement systems require usually the generation of a movement more accurate than the precision desired, what is usually very expensive, difficult to ensure and maintain, and only valid in controlled laboratory conditions.

This new system enables to use a roto-translation system not needing such accuracy, as the inaccuracies are pre-calibrated and then compensated by software. Even the eccentricity of the rotation system due to the asymmetry of the ball bearings is compensated for. Also, a reference piece allows fast automatic recalibration (1 more second) and compensation of variations in the system (as thermal expansion), that allows the system to operate in a stable manner in non-controlled environments.

The design of the system permits also to easily adapt to all the production range of diameters and heights, with a simple manual operation and an automatic recalibration. Also, adaptation to other pieces with cylindrical symmetry is fast and easy.

References

[1] International Organisation for Standardisation; ISO1101, "Technical drawings-Geometrical tolerancing –Tolerancing of form , orientation, location and run-out".
[2] G.Y. Sirat and D. Psaltis; "Conoscopic holography" Opt. Lett.10, (1985)
[3] G.Y. Sirat; "Conoscopic holography". Basis principles and physical basis" J. Opt. Soc. Am. (1992)
[4] Optical Metrology Limited; "Technical specifications for Conoprobe 1000, mini 3000 and Conoscan".
[5] International Organisation for Standardisation; ISO 5725-2:1994, "Accuracy of measurement methods and results. Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method".