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THE INFLUENCE OF THERMAL DEFORMATIONS OF INTERIOR DIAMETER GAUGES OVER THE PRECISION FOR PRODUCT QUALITY CONTROL

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Abstract. *Almost all manufacturing processes are involving a heat release during operation and in most cases this will increase the ambient temperature in production. Taking in consideration that environment temperature is influencing the active dimensions elements of interior diameter gauges, in the paper are presented the theoretical and experimental results obtained with the finite element method, for the thermal deformation variation by taking in consideration temperature, form and dimensions of interior diameter gauges.*
Keywords: *interior diameter gauge, finite element, product quality control, thermal deformations*

1. INTRODUCTION

Gauges are instruments for control used for limitative dimensional and geometrical control deviation of the machined surfaces, being highly productive, economical and practical, which have no need for highly trained operators, used in serial and mass production conditions.
From economical point of view, quality verification is a non-productive time, which increases the cost of manufacturing, for this reason this process must be limited to an absolute necessarily in each process step of the product manufacturing.
The problem of producing quality products is imposed by economic efficiency considerate. In this way it can be recognized an increased (by reason of raw materials and energy crises and markets globalization) balance of the entrance costs in the manufacturing process (raw materials, energy, purchased parts), which can get sometimes to over 50% of product final cost (finite products, spare parts, etc.) [4].
Interior diameter gauges are not complex control devices and do not need special training to operate them and maybe that's way sometimes the focus, as a production measurement and control device, is not that high as in the case of complex measurement device. The aim of the paper is to demonstrate that interior diameter gauges could have high impact in production numbers and most important in the quality assurance, with in implications in after sales or customer dissatisfaction.

2. ACTUAL PRINCIPLES FOR SELECTION OF METHODS AND INSTRUMENTS FOR CONTROL OF PRODUCT QUALITY

Taking in consideration all 5 M's (man, machine, method, material and medium) we can determine that control devices are not analyzed from environment point of view when the need of a quality verification operation is imposed by the project. The most common situation in production areas is when the product is verified for quality assurance in different stages and places in the production floor and a final verification in the quality/ verification floor.
Factors that are contributing to the rational and efficient selection of methods and instruments for control of product quality taken from specialized literature can be found below [1]:

- The nature and character of the measured and controlled parameters [7];
- Tolerance (dimensional, geometrical, micro-geometrical) of verified parameters [1];
- Production volume (or the production batches: unique, serial, mass production) [3];
- Error limit of the measurement/ control instrument or method [1, 2, 4];
- Safety of the measurement/ control instrument [8];

- Measurement/ Control operation productivity [8];
- Measurement/ Control operation costs [5], [9];
- Measurement method/ instrument complexity and necessary operator qualifications [6];

3. FINITE ELEMENT MODELLING FOR THE SHAFT GAUGE

A real production situation, where the product is verified in different stages and different locations during manufacturing, means that the product will be verified in at different temperature, for the situation below it was chosen a turning process, where the pieces are first verified at a temperature of 37°C (uncontrolled environment conditions), then moves to a second operation, removing burr for example, and then the final control operated at a temperature of 20±2°C (controlled environment conditions).

For the simulation the interior diameter gauge material used is RP3, which has the chemical composition listed in Table 1 and international equivalence in Table 2.

Catia V5 simulation tool has the next properties:

- Young Modulus= 2e+011[N_m2]= $2*10^{11}$[N/m^2];
- Poisson Ratio= 0.266;
- Density= 7860 [kg/m^3];
- Thermal expansion= 1.17e-005[_Kdeg]= $1.17*10^{-5}$[1/Kdeg];
- Yield Strenght= 2.5e+008[N_m2]=$2.5*10^8$[N/m^2];

Table 1. Brand and chemical compozition for high-speed steal [10]

Steal brand	Chemical composition [%]					
	C	W	Cr	V	Mo	Co
Rp1	0.90÷1.00	9.00÷10.00	3.8÷4.4	2.3÷2.7	≤1.00	5.0÷6.0
Rp2	0.75÷0.83	17.5÷18.5	3.8÷4.5	1.4÷1.7	0.5÷0.08	4.5÷5.0
Rp3	0.7÷0.78	17.5÷18.5	3.8÷4.5	1÷1.2	≤0.6	≤0.6
Rp4	1.17÷1.27	6.0÷6.7	3.8÷4.5	2.7÷3.2	4.7÷5.2	-
Rp5	0.84÷0.94	6.0÷6.7	3.8÷4.5	1.7÷2.0	4.7÷5.2	≤0.6
Rp9	0.95÷1.03	2.7÷3.0	3.8÷4.5	2.2÷2.5	2.5÷2.8	≤0.6
Rp10	0.78÷0.86	1.5÷2.0	3.8÷4.2	1.0÷1.3	8.0÷9.2	≤0.6
Rp11	0.97-1.07	1.5÷2.0	3.8÷4.2	1.8÷2.2	9.0÷9.2	≤0.6

Table 2. High-speed steal symbols and international equivalance [10]

SR	JIS	GOST	Werkstoff	Bohler	AISI/ SAE	UNE
Rp1	-	-	-	-	-	-
Rp2	SKH3	-	W.1.3255	-	T4	F.5530 18-1-1-5
Rp3	SKH2	R18	W.1.3255	S200	T1	F.5520 18-0-1
Rp4	SKH52 SKH53	-	W.1.3344	S607	M3	F.5605 6-5-2
Rp5	SKH51	(R6AM5) R6M5	W.1.3343	S600	M2	F.5604 6-5-2
Rp9	-	-	W.1.3333	-	-	-
Rp10	-	-	W.1.3346	S401	H41 M1	-
Rp11	-	-	W.1.3348	S400	M7	F.5607 2-9-2
Rp10 Sp	SKH59	-	W.1.3247	S500	M42	F.5617 2-10-1-8

For simulation purposes the interior diameter gauge diameter was simulated for 9 specific dimensions intervals, from which the most relevant diameter was calculated with relation (1), where D_{min} is the minimal diameter from the group and D_{max} is the maximal one. The intervals and the calculation result are presented in Table 3.

$$D = \sqrt{D_{min} * D_{max}} \quad (1)$$

Table 3. Diameter dimensions intervals

Diameter [mm]	Min [mm]	Max [mm]
7.745	6	10
23.237	18	30
44.721	40	50
109.544	100	120
129.614	120	140
149.666	140	160
169.705	160	180

Modelling of the representative device is presented in Fig.1 and for all the remaining diameters the piece was modified with specific interior diameter gauge geometrical parameters.

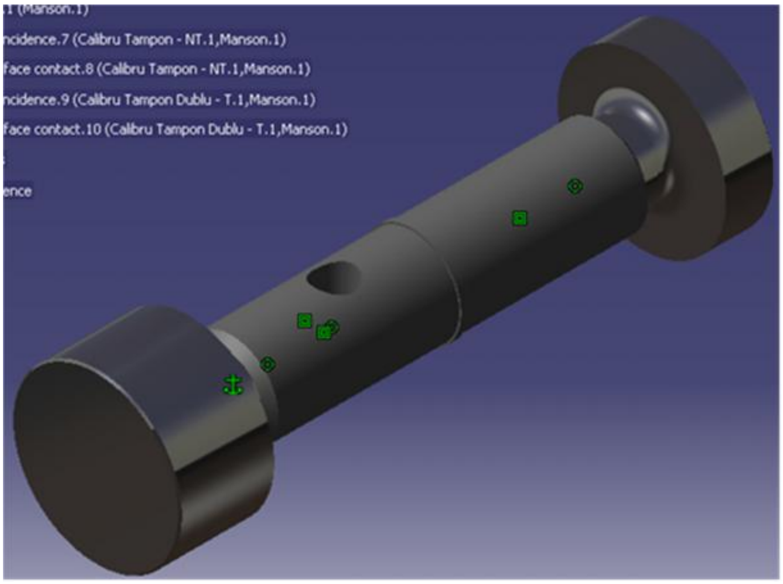

Figure. 1. Interior diameter gauge simulated in Catia V5

Simulation result, with Gauss R6 method, Clamp fixation at a temperature of T_1=310.15°K (37°C) considering the gauge at a temperature of T_0= 20°C, is presented in Fig. 2.
The results obtained by modelling and simulating the interior diameter gauge with the finite element method are presented in Table 4.
Finite element results showed a thermal expansion from 0.002mm – 0.034mm which can sometimes, depending on the tolerance of the product, make the difference between a good or bad judged piece. Most important is that the example used a turning process as the manufacturing operation and it’s easy to understand that if the gauge is used by hand and in higher temperature environment (most of machining environments are hot

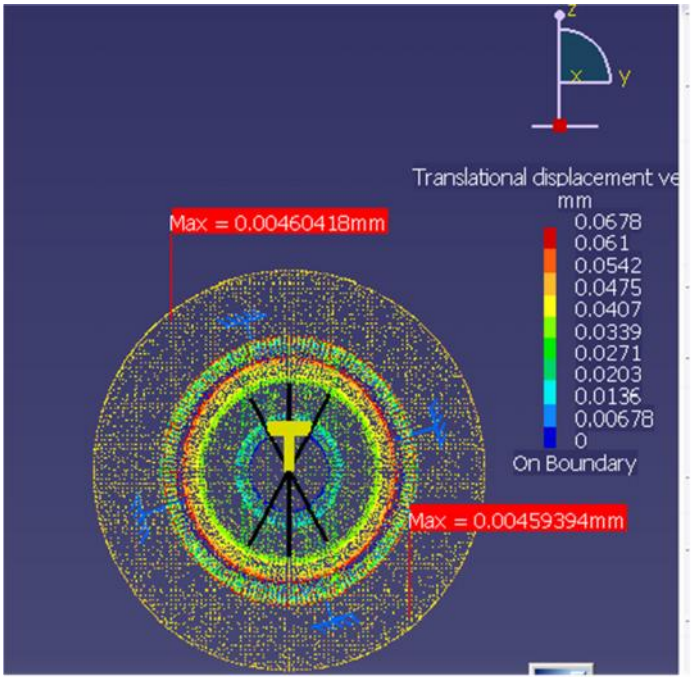

Figure. 2. Interior diameter gauge finite element simulation for D=44.72mm

Table 4. Finite element simulation results for NO NOGO shaft gauge

Nr.crt.	D [mm]	t [° C]	Displacement Magnitude Right Surface [mm]	Displacement Magnitude Left Surface "GO" [mm]	Displacement Magnitude Left Surface "NOGO" [mm]	Thermal expansion [mm]
1	**7.745**	37	0.001	0.001	0.001	0.002
2	**23.237**	37	0.002	0.002	0.002	0.005
3	**44.721**	37	0.004	0.004	0.004	0.009
4	**109.544**	37	0.011	0.011	0.011	0.022
5	**129.614**	37	0.013	0.013	0.013	0.026
6	**149.666**	37	0.015	0.015	0.015	0.030
7	**169.705**	37	0.017	0.017	0.017	0.034

due to the processes that generates heat) this kind of expansion will first give a wrong input to the operator that has to setup the machine and the product will deviate from the mean value (nominal tolerance) and second the production batch will have a percentage scrapped when the products will be final inspected at T= 20°C.

5. CONCLUSIONS

Taking in consideration all presented in this paper, it can come off next conclusions and recommendations:

1. From theoretical point of view, the shape of the control end of the gauge corresponds to the shape of the conjugate piece which is being verified, but as most production facilities have two separate floors, one for production and one for product quality verification, where due to legislation might be that temperature is different and even if the operator and the method are the same, it can be seen a different quality control outcome.
2. Depending on the diameter used the expansion due to higher temperature can have values between 0.002-0.034mm, which can sometimes make the difference between producing a good part or a bad part, by giving wrong input to the setup operator.
3. High precision products are much more affected by temperature expansion then the normal ones and by calculating a breakdown between products, high precision vs lower precision, can raise a business case to improve devices, methods and even the production environment.
4. The cost for the equipment and method used for product quality verification must be justified and balanced by the precision and productivity of them.
5. The device and method complexity for product quality verification takes in consideration: productivity, verification cost, but also the qualifications needed by the quality inspector: a higher complexity could mean a simple

method and an increased productivity which doesn't necessarily mean a higher qualification for the quality inspector, instead a higher complexity and method means for the quality inspector a higher qualification, which is only justified by a very big productivity.

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