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HIGH SPEED MACHINING OF ALUMINIUM GEAR BOX WITHOUT TEMPERATURE STABILIZATION

Summary. At the present time both clutch and mechanism housings, which are the main components from automotive gear boxes, are made of special aluminium alloys. These alloys are extremely light when compared with steel, making them a perfect choice to mitigate the cars weight and machining costs. Nonetheless they possess a high thermal expansion coefficient, which can be considered a major disadvantage since it makes necessary to pay extraordinary attention to dimensional variations during the production cycle due to temperature deviations. High speed machining of precision components made of aluminium requests thus their temperature to become previously stable. This procedure is the only way to force dimensions to stay inside its tolerance intervals. The main purpose of the present work was to assess the possibility to avoid the use of special ovens to make the clutch housing temperature become stable prior to machining. The dimensional stabilization of 40 sample parts, pre-heated at three temperature levels, was accomplished through the use of this system. The achieved results were made possible by analysing the part's temperature at the machine's entrance, the machine's interior temperature, 35 measured dimensions and their tolerance intervals as well as the average temperature deviations of each of the five considered batches. By analysing the obtained results in detail it was possible to determine which dimensions show high sensitiveness to temperature (high correlation between dimension's variation and temperature). Among these dimensions we can point out the ones related with depth, since they display the highest deviations due to temperature. Being a work with practical application it was possible to confirm the benefit of using this methodology by achieving significant enhancements on production efficiency, energy savings and reduction on maintenance costs, through the application of small adjustments to the machining sequence and by adopting a systematic tuning of certain dimensions.

SZYBKA OBRÓBKA ALUMINIOWYCH OBUDÓW SKRZYŃ BIEGÓW BEZ STABILIZACJI TEMPERATUROWEJ

Streszczenie. Obecnie zarówno sprzęgło, jak i mechanizm przekładniowy, które są głównymi komponentami skrzyń biegów, umieszczone są w obudowie wykonanej ze specjalnych stopów aluminium. Stopy te są znacznie lżejsze w porównaniu ze stalą, powoduje to że są one doskonałym wyborem, by zmniejszyć wagę samochodów oraz koszty produkcji. Niemniej jednak materiały te posiadają wysoki współczynnik rozszerzalności cieplnej, który może zostać uznany ich główna wadą. Powoduje to że koniecznym stało się zwracanie dużej uwagi na utrzymanie wariantów wymiarowych podczas obróbki charakteryzującej się zmianami temperatury. Wysoka szybkość obróbki precyzyjnych komponentów wykonanych z aluminium spowodowała konieczność wcześniejszego ich podgrzewania w celu uniknięcia zmian temperatury podczas obróbki. Takie zabieg jest jedynym sposobem, aby zachować odpowiednią tolerancję wymiarową. Głównym celem niniejszej pracy była ocena możliwości, uniknięcia użycia specjalnych pieców wstępnie podgrzewających elementy przed obróbką w celu zapewnienia stabilizacji termicznej podczas obróbki. W pracy przeanalizowano możliwość zastosowania specjalnych komór z natryskowym systemem chłodzenia olejowego. Analiza osiągniętych wyników była możliwa poprzez pomiar temperatur na wejściu do maszyny oraz w jej wnętrzu. Pomiary przeprowadzono dla 35 próbek, których wymiary oraz tolerancję mierzono. Szczegółowa analiza pozwoliła stwierdzić, które z wymiarów wykazują się dużą wrażliwością na zmiany temperatury (wysoka korelacja między odmianą wymiaru i temperaturą). Pomiędzy wytypowanymi wymiarami najwrażliwszymi okazały się wymiary związane z głębokością. Uzyskane wyniki pozwoliły potwierdzić korzyści z używania opracowanej metody. Metoda ta pozwala na znaczne oszczędności energii oraz zwiększenie efektywności produkcji.

1. INTRODUCTION

In the automobile industry the use of aluminium is more and more frequent; its use doubles since 1990. This increase is due to the strong need of weight reduction in automobile, contributing to accomplish the growing demands of reducing the derived atmospheric emissions of fuel fossils. But, the use of aluminium also allows to increase the active security, its excellent ductility and aptitude of absorption of energy, allows the application in all the cinematic components of the vehicle. A reduction of 100Kg in an automobile weight, without modifying the engine, means a reduction of nine grams per Km in the emission of CO_2, that is can reach a reduction of consumption of 800kg of fuel in the useful life of an automobile [1].

While several materials can be used to reduce vehicle mass, aluminium offers not only significant advantages during the use stage, but in particular, also in the end-of-life stage. The excellent recyclability of aluminium, together with its high scrap value and the low energy needs during recycling (only about 5% energy need required by primary production), make aluminium lightweight solutions highly desirable. In the last years it is significant the progresses in the cast technology and machination of aluminium. The demand for aluminium in the transport sector has been increasing year by year. In 2005, up to 30% of wrought and casting alloys used globally were used in cars, commercial vehicles, aircraft, trains and ships. The current cast process is made by injection in high pressure to increase the production speed and to improve the mechanical properties.

The centres of high-speed machination are more and more fast, high precision, simpler of operating and more flexible. Since the Nineties the velocity of displacement of the axes and the rotation of the tree duplicated and the acceleration quadruplicated. Today the precision allows determining the diameters for interpolation [2]. With these advantages and with the need to adapt the product quickly (larger flexibility) to the consumer's needs and the constant increase of the market niches, it did that the automobile industry to more and more using the tooling centres as a replacement of the transfer lines. The increase of the precision and speed of cut is also due to the cut tools properties. It's improvement is justified by the use of PCD (polycarbonate diamond). But, one of the inconveniences of the high-speed centres, due to its high speed the piece comes out soon finished, if the piece has problems of temperature stability, like aluminium, it previously requires temperature stabilization.

The aluminium introduces a serious problem in the machining, it's high coefficient of thermal dilation, about of 0.020 to 0.025mm for one degree Celsius, implicates that in a difference of 10ºC can create differences of dimensions about 0.25mm. In reality these geometric changes are incompatible with the tolerances in the production of the automobile industry. More and more the demanded tolerances in dimensions are squeezed in a way to increase the cinematic performing of the work of the elements of the vehicles. The resolution of this problem is in machining the pieces to a constant temperature, usually among 20-22ºC. The solutions more common applied for the automotive industry are: - Temperature of the building controlled; - Pré-stabilization of the pieces temperature in oven; - Stabilization of the temperature inside of the machining cut centre through cut oil [3, 4].

Aluminium alloys for the automotive industry usually contain elements to improve their mechanical properties such as fluidity during casting. Silicon is responsible for the improvement of mechanical resistance to the corrosion and fluidity during the casting process. The Manganese besides the fluidity increases the mechanical resistance because it forms precipitate very hard that can increase more than 10 times the mechanical resistance of pure aluminium. Copper improves the mechanical resistance and it facilitates the machining unlike Silicon. The cast of high pressure turns the process fast, efficient and relatively cheaply [5, 6].

This work analyzes a gear box with a mass of 9,5 kg. This piece was usually stabilized in a tunnel refrigerated to the temperature 22± 2ºC for 8 minutes. The objective of this study is the deactivation of these cooling tunnels and to pass the temperature stabilization of the inside machining centre, during the cut process. It is necessary to identify the critical dimensions and which cares to have for us to respect the tolerances.

2. MATERIALS AND METHODS

The aluminium alloy commonly used in the gear box is AlSi9Cu3, with composition shown in Tab. 1. These pieces are complex, of difficult casting and with many machining characteristics. The coefficient of thermal dilation of this alloy is 0.0205mm per Celsius degree (NF EN10002-1), there is need to do the machining tooling with a very small difference of temperature in relation to the measurement the dimensions of all characteristic in pieces [5-7].

Table 1

Composition of AlSi9Cu3 (standard EN 1676:1996)

	COMPOSITION (wt %)									
	Fe	Si	Cu	Zn	Mg	Mn	Ni	Pb	Sn	Ti
Al Si9Cu3(Fe)	<1.30	8.0-11.0	2.0-4.0	<1.20	0.05-0.55	<0.60	<0.55	<0.35	<0.25	<0.25

The pieces, fig. 1, they arrive to the entrance of the work line (OP100), later they are inserted in a rolling carpet crossing a refrigerated tunnel. They stay in this tunnel during at least 8 minutes (OP 105) allowing the stabilization of it's temperature, only after having numbered, they are introduced in the machining centre: -first vertical assembly (OP110) for the machining of complete interior area and later in the horizontal assembly (OP 120) to be executed the periphery characteristics. The temperature of the tunnel is of 22 ± 2ºC, gotten through of heat exchanges controlled by PLC. During the machining process the cut oil is at the temperature of 21± 1.5ºC maintained constant for the oil central through heat exchanges. The temperature of the tunnel and the oil is controlled for each team, besides it exist a monitoring system prepared to shoot a warning if there is one deviation.

After having machining the gear box they are measured in local control or in the 3D machine. In local control the characteristics are measured for which there is a fast wear and the tools have an interval of tolerance very small. In the 3D machine all characteristics of the gear box are measured. This control is arduous and it is done after the stabilization of the temperature during one hour.

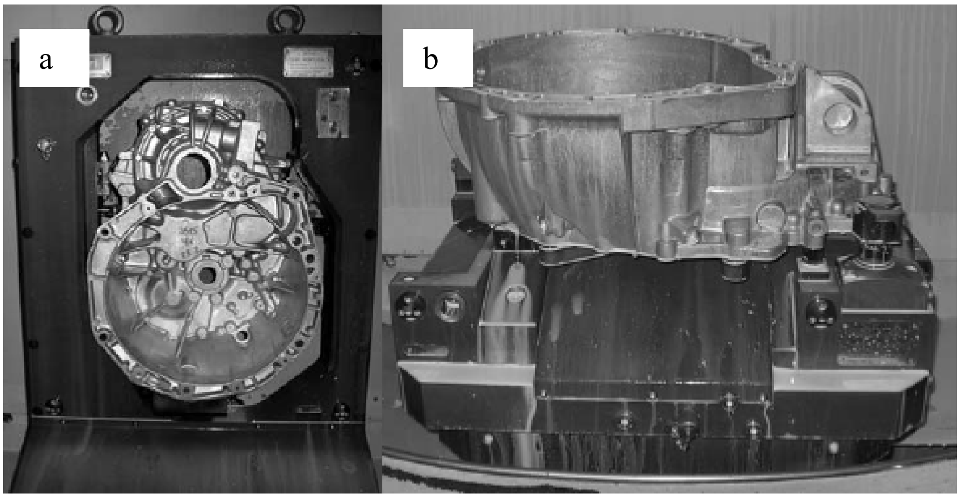

Fig. 1. Gear box into machining centre: a) vertical assembly; b) horizontal assembly
Rys. 1. Skrzynia biegów w maszynie obrabiającej: a) pionowy montaż; b) poziomy montaż

3. EXPERIMENTAL

The experimental work has as objective to evaluate the impact of the temperature difference in the gear box, during it's high speed machining and to consider the deactivation of the oven responsible for the temperature stabilization of the pieces. After that, knowing the influence of temperature in dimensions behaviour, it can be introduced in the execution program the work of all sequence characteristics (machining). Understanding the dimensional changes during the sequence of machining work it allows developing stabilization through the shower system using the cut oil without committing the quality of the accomplished service.

The experimental procedure was done with the following information. Specimen piece: gear box model "CED ND0", pattern 2.2.2 of Renault; Mechanical process: Machining Centre "DMG 63H"; Temperatures Sensor: "TESTO 615" to measure the room temperature and: "HANNA Instruments HI91530K" to measure the specimen temperature; 3D Machining for three-dimensional control: "ZEISS PRISMO"; Data acquisition and interpolation: "QS-STAT".

In the way to do a comparative test, they were made 5 groups of pieces following with different temperatures, just as display in table 2. In the first line it has the group number, in the second line the temperature of stabilization into oven, in the third line the temperature measured in the specimen (average temperature), in the fourth line the specimen number of control. In the groups 1, 3 and 5 were use the ordinary conditions of production, that is a stabilized of temperature during at least 8 minutes.

Table 2

Five groups of specimens machining in several temperatures

				Group 1										**Group 2**							**Group 3**			
				22º C										**30º C**							**22º C**			
				21.6º C										31.8º C							-			
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40

					Group 4							**Group 5**		
					40º C							**22º C**		
					39.2º C							-		
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55

If the objective of this test is to evaluate the viability of a substitute to the stabilization of the temperature in the oven for the shower of the piece (gear box) through the cut oil, it is necessary that the time of shower, more the time to introduce and to remove the piece in the vertical assembly (OP110) and added it mark, should be inferior at the time of machining (OP 120), horizontal assembly in simultaneous operation. This way there won't be any stop in the machining process, because the time of bath of the piece in the vertical assembly is hidden by the execution of the characteristics in the horizontal assembly.

As the time of cycle of “OP120” is of three minutes and 22 seconds, the sum of the time of experimental procedure has to be inferior. Like this, the time was distributed in the following way: One minute - Simulation of stop of the machine centre for piece to wait. This time has used like margin time of the operator, in an usual situation this operator answers before four machine centres therefore, it is not immediately available as soon as it finishes the operation “OP110”; 35 seconds - Removal of the machined piece and cleaning of the assembly. To mark the next piece to be machined, and it placement in the machine centre. One minute and 43 seconds – Staying in the position subject to the shower.

4. RESULTS AND DISCUSSION

After the manufactured piece and its dimensional control in the 3D machine, with temperature stabilization during, at least, one hour results can be seen. The dimensional control of the whole piece it implicates the measure of 35 characteristics to multiply of 40 analyzed pieces that is a total of 1400 measures. Due to the enormous amount of information a graphic methodology seems to be the simplest way to show all the contents. On fig. 2 to 5 the characteristics are presented machining in the procedure “OP110”. The characteristics “OP120” are not affected for the initial temperature because during the machining procedure “OP110” the gear box is permanently to be taken a shower of cut oil.

In the gear box there are two different faces: - the engine face, named by face 1000 and the mechanism face, designated by face 2000. The characteristics of those faces are presented in the following figures. The characteristics with intervals of tolerance more squeezed are the: - 2001: primary tree; - 2002: secondary tree; - 2003: Differential; - 2004: Go-Back axes; - 2105 and 2106: distance between axes; - 1101 and 1102: engine centred; - between axes and engine centred; - Face 2000 (mechanism face); - Face 1000 (engine face).

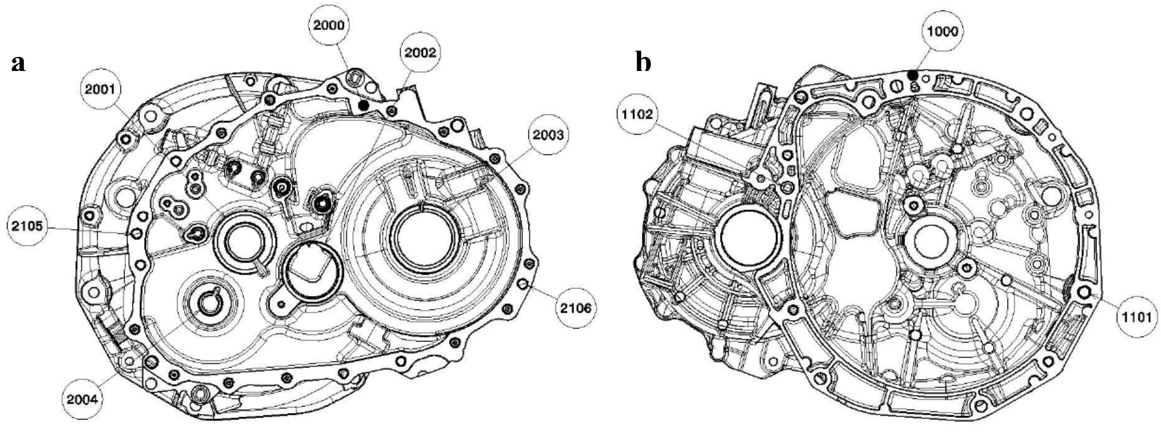

Fig. 2. Surface: a) mechanism of gear box, b) engine of gear box
Rys. 2. Skrzynia biegów od strony: a) mechanizmów przekładniowych, b) silnika

In the fig. 3 are showed examples of analyses dimensions (characteristics) and your tolerances.

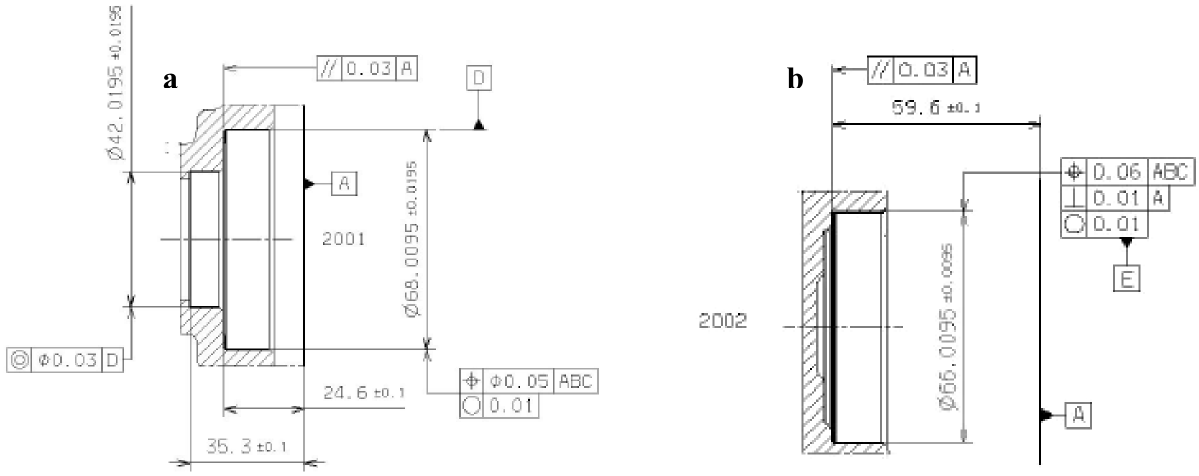

Fig. 3. Characteristic: a) 2001 of primary tree, b) 2002 of secondary tree
Rys. 3. Wymiary: a) 2001 drzewa podstawowego, b) 2002 drzewa drugorzędnego

The organization of the all information in graphic representation is presented in Table 3 and also:
- X axes: number of pieces;
- Y axes (left): dimensions values;
- Y axes (right): temperature value (piece and environment). Each group are one line to show the sequence of dimension.

Table 3

Designation of legends in graphic representation

Notation	Designation	Observations
T_{Peca}	Temperature of the piece	The temperature of the gear box is measure before it inside the machine centre.
T_{Amb}	Temperature of the environment	The temperature of air.
L1, L2, L3, L4, L5	Average value of group 1,2,3,4 and 5	Average distance of all measurement determined for each group.
LS	High limit	Superior limit of the experimental measure.
LI	Low limit	Inferior limit of the experimental measure.
Obj	Objective value	Centred or exact value.
ALS	Higher work value	Maximum value limits before centred (+80% of IT)
ALI	Low work value	Minimum value limits before centred (-80% of IT)
IT	Deviation	Maximum deviation between the group "i" and the group 1 (reference)
Correl.	Correlation coefficient	Relation between the values and the temperature changes.

Fig. 4 are represented the experiment measurement of characteristic #043, corresponding of one diameter ϕ68H6 of "primary three" (2001), see again fig. 5.

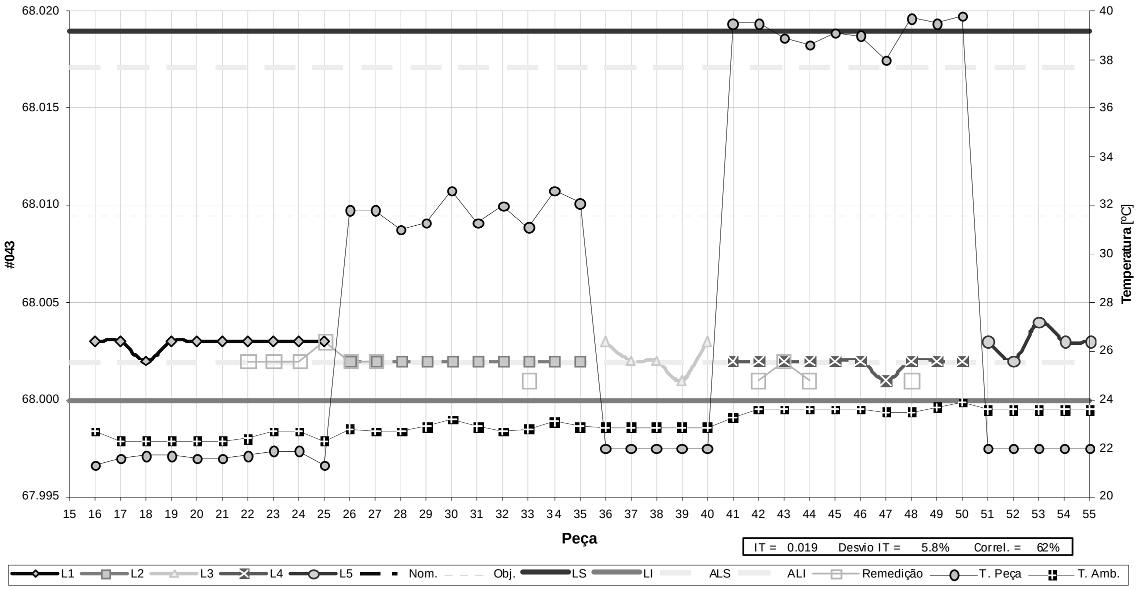

Fig. 4. Dimensions analysis of characteristic #043 (diameter ϕ68H6)
Rys. 4. Analiza wymiarów #043 (wymiar ϕ68H6)

Observating the relationship between temperature and the dimensions of gear box it as a correlation of 62%, but a thoughtful analysis shows only a deviation of 5.8% and this represent about 0.001mm, therefore it is not significant. Fig. 5 show the measurement on the perpendicularity between the characteristic of “2001” in relation to the face “2000”, see also fig. 4.

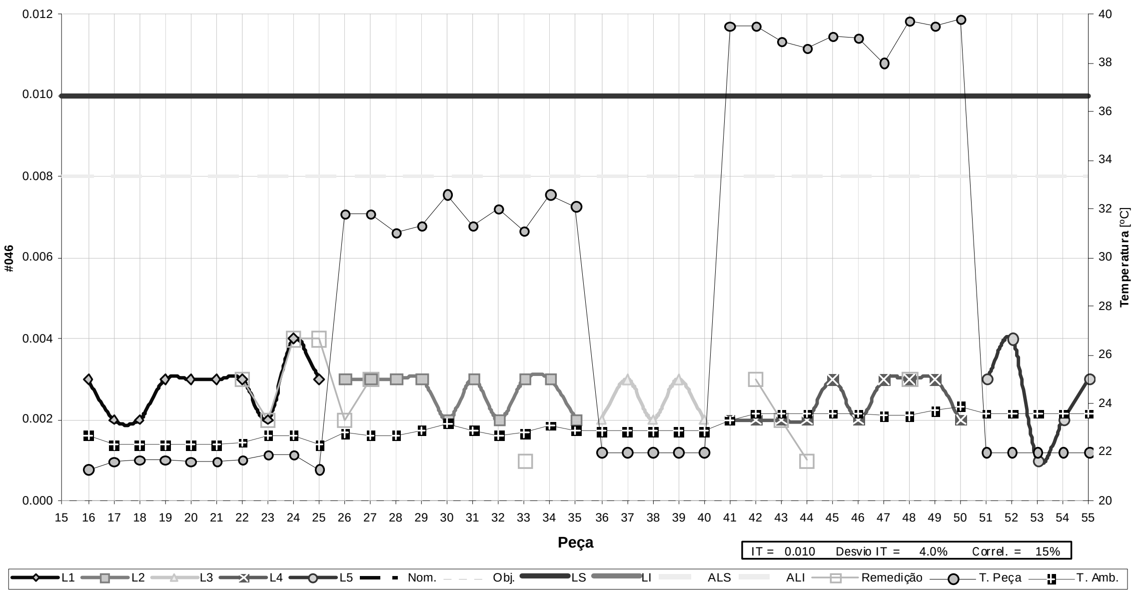

Fig. 5. Dimensions analysis of characteristic #046 (perpendicularity of hole ϕ68H6)
Rys. 5. Analiza wymiarów #046 (stałość wymiaru otworu ϕ68H6)

It can be observed that the deviation and the correlation are also low 4% and 15% respectively. These values were of waiting, therefore just if the face "2000" had great deformations, that doesn't happen since this is planned for twice (milling and finishing), after the gear box already to have about 13 minutes of shower.

In fig. 6 the measures of the concentricity of the characteristic Ø42H7 are acted in relation to Ø68H6 (see again fig. 5). The deviation is of 13.7% and the correlation is of 1%. The high value of the deviation is due essentially to the dispersion of values of the group 1 and group 4. A new repetition in the measurement allowed obtaining a correlation 4% and a deviation of 5.3%, what are more reasonable values. In the reality the quality of the finish of these characteristics only depends on the tool, and both are executed with the same tool.

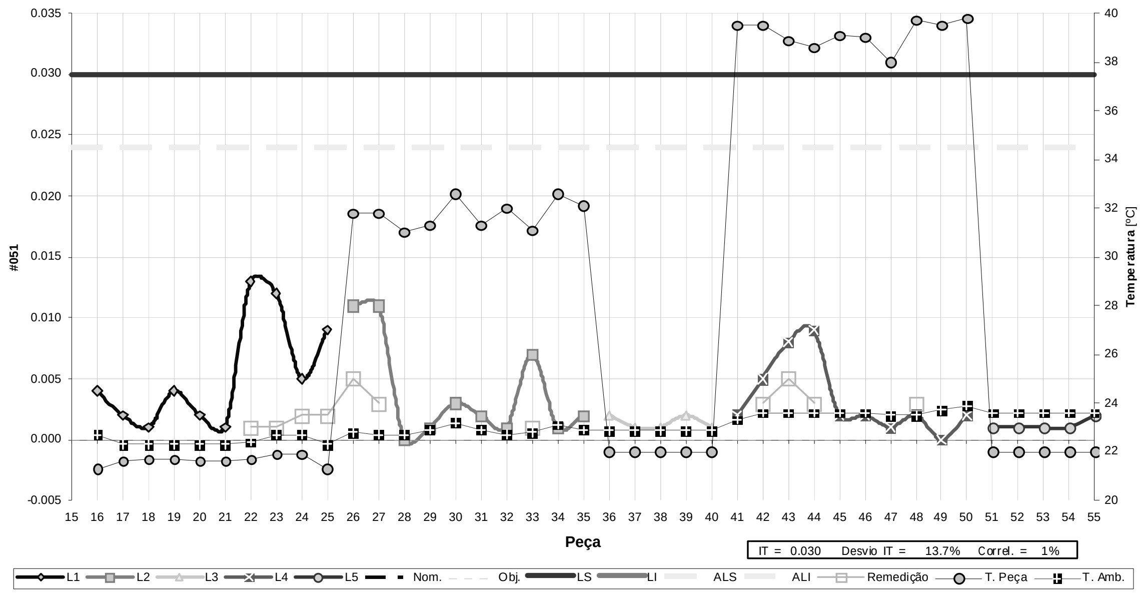

Fig. 6. Dimensions analysis of characteristic #051 (concentricity of holes ϕ42H7 and ϕ68H6)
Rys. 6. Analiza wymiarów #051 (współosiowość otworów ϕ42H7 i ϕ68H6)

This result implicates that there is need to regulate the dimension more times, that is the dimension of the piece should be closer to the nominal dimension. It requires a process dimension with the objective of monitoring the centre of the piece in brute in relation to the planned surface, this way it cannot take the risk there to be a high-thickness in the holes to machine.

Fig. 7 shows the analysis of characteristic "2002-16". It is verified that the gear box continues shrinkage even after having planned the reference of the piece. The gear box come inside from the machining centre with the stabilized temperature is always larger than when it enters with the highest temperature.

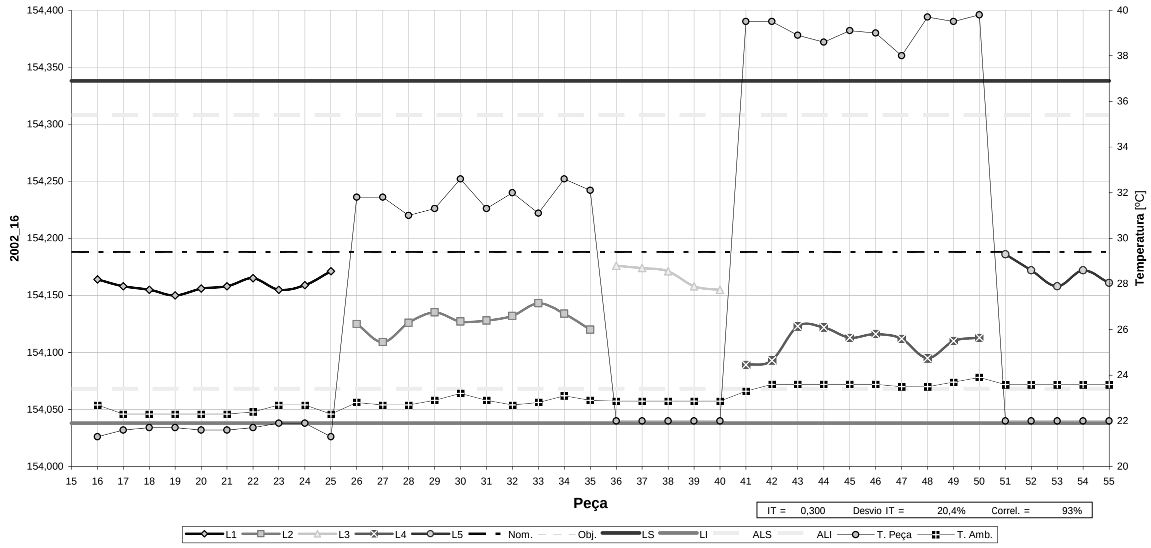

Fig. 7. Dimensions analysis of characteristic "2002-16" (distance between 2002 surface and raw locating)
Rys. 7. Analiza wymiarów "2002-16" (odległość pomiędzy powierzchnią 2002 oraz usytuowaniem otarcia)

5. CONCLUSIONS

In this work is presented examples of the experimental measures of the characteristics. However, the developed research was very vast, being analyzed all of the dimensional variations in the characteristics of the pieces of all groups. Observing all results it is verified that the deviations of the characteristics where the correlation with the temperature is more significant in the depth direction and where the dimensions increase in relation to the reference axis. This problem was found in the dimensions: "2001-13" - support of the roller-bearing of the primary tree (reference A); "2317-05" - location of the hole of centred of the box (hole of the periphery). With the exception of the characteristic "2002-16" distance among the face 2002 (coordinate reference of the piece) and the centred (origin brute), that it is a dimension of process, and the dimension #024 consists of the location of the characteristic "1102" corresponding to the entry of the piece in the hole of the engine centred.

All the other dimensions have a percentage variation relatively low, below the 15%. Like, this deviation doesn't put in cause the quality of the final piece. It is verified with the characteristic "2002-16", of gear box continues shrinkage even after the axes reference of the piece to be machined. The effectiveness of this procedure, substituting the temperature stabilization of the pieces in oven before the machining, it demands a very rigid monitorization in way to maintain these closer dimensions of the nominal dimensions.

The advantages of the application of the bath system inside of the machining centre, with the oil of cut in homogeneous way, it can refrigerate the gear box very high, namely: -elimination of the oven of temperature stabilization, that is, reduction of the energy consumption, reduction of the time of production stop and elimination of the fee of the maintenance. However it is necessary a small investment, namely: -controllers to maintain constant the flow of cut oil; - system of shower to refrigerate the gear box; -monitorization of the system and warnings for the case of the bath is not to be efficient; -implementation of the minimum time of shower in the machining program.

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