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MECHANICAL ELEMENTS: DIMENSIONAL ANALYSIS OF THE FITS

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Abstract: In the mechanical elements production, when a piece is manufactured, the specifications are available, which can be dimensional, strength, weight or any other. The obtained product is accepted when it is within a tolerance margin, which means that it will not have an exact measurement as predicted. To achieve interchangeability, it is just necessary to rely on dimensional tolerance. It is classified for each type of work and the corresponding one is assigned in each case, according to the working conditions or the purpose of the work. It is taken into account that the fit consists in the dimensional union of two pieces and it is determined by the difference between their dimensions, given by their respective tolerances intervals, before their assembly; that is, by the fits´ magnitude obtained in the union. This research work has carried out a dimensional analysis of the adjustment of three couplings, belonging to the speed box of a UAZ 469 Jeep, to the feeding system of a matches manufacturing machine and to a Yung-6 tractor. The authors have identified the main problems during the manufacturing of the different machine elements; that lead to economic losses for the enterprise and for the country.
Keywords: mechanical elements, interchangeability, dimensional tolerance, dimensional analysis, fits

1. TEXT LAYOUT

To necessity that the processes of quality´s control are compatible and be up-to-date with the guides and the norms, demands from the whole process a continuous improvement and a constant preparation of the personnel related with the metrological confirmation. (4)(11)

In order to facilitate the interchangeability of pieces, the countries have established charts of tolerances, getting ready Systems of Limits and Adjustments whose application became international with the application of the norms International Organization for Standardization (ISO). In Cuba, to assure the pieces´ interchangeability, there is the Norma Cubana NC 16-30 "Fits and Tolerances", which is concordant with the ISO 286/1 and ISO 286/2, used at international level. (3)(6)(8)

When the manufactory of a part is required, the mechanical production elements needs the specifications. So that the piece can enter in service, it should complete certain characteristics. The obtained product is accepted when it is in a margin of tolerances, what means that this it won't have an exact measure to the one predicted. While limits and fits apply to all sorts of mating parts, their main use is for regulating the sizes of mating shafts and holes for best performance.

The fit consists in the dimensional union of two pieces and it is determined by the difference between their dimensions, given by their respective tolerances intervals, before their assembly; that is, by the fits´ magnitude obtained in the union.

ISO have standardized fits in three classes: clearance, transition and interference. Each class has a variety of options available for choosing the correct one for a specific application. The choice of an engineering fit determines whether the two parts can move relative to each other in case of a clearance fit, or act as a whole in case of a tight interference fit. (7)(9)

In process improvement efforts, the process capability index is a statistical measure of process capability: the ability of a process to produce output within specification limits. The concept of process capability only holds meaning for processes that are in a state of statistical control. Process capability indices measure how much "natural variation" a process experiences relative to its specification limits and allows different processes to be compared with respect to how well an organization controls them. (1)(10)

The input of a process usually has at least one or more measurable characteristics that are used to specify outputs. These can be analyzed statistically; where the output data shows a normal distribution the process can be described by the process mean (average) and the standard deviation. A process needs to be established with appropriate process controls in place. The output of a process is expected to meet customer requirements, specifications, or engineering tolerances. Engineers can conduct a process capability study to determine the extent to which the process can meet these expectations. The ability of a process to meet specifications can be expressed as a single number using a process capability index (2)(5).

Below is a fit´s analysis for different pieces belonging to a UAZ 469 Jeep, a matches machine and a Yung-6 Tractor, in which the process´ capacity coefficients are restricted to values greater than or equal to 1,33 and process´ critical capacity to values greater than or equal to 1,0 for the process to be capable.

2. ANALYSIS OF AN INDETERMINATE ADJUSTMENT

In this case a measurements´ simulation for the shaft of fixed train (shaft) and for fixed train (hole) with a setting of Ø40 H7 / k6 is made; these pieces belong to the speed box of a UAZ 469 Jeep.

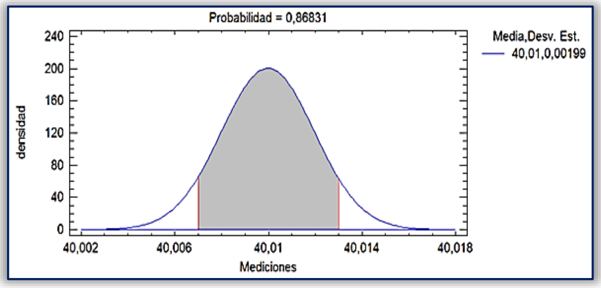

Figure 1. Graph of the simulated dimensions´ values of the fixed trains haft. Own elaboration

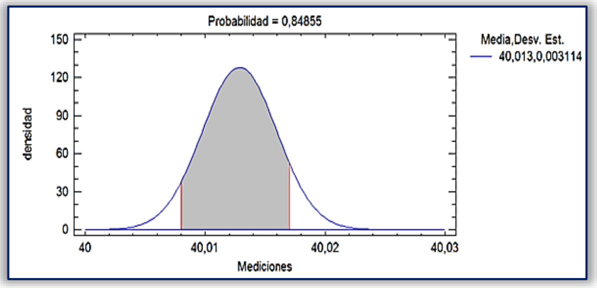

Figure 2. Graph of the simulated dimensions´ values of the fixed train. Own elaboration

In this case a measurements´ simulation of the shafts of fixed train (shaft) and fixed train (hole) with a setting of Ø40 H7/k6 is made; these pieces belong to the speed box of a UAZ 469 Jeep. For this analysis it is decided to restrict Cp≥1,33 and Cpk≥1,0, in order to obtain a capable process.

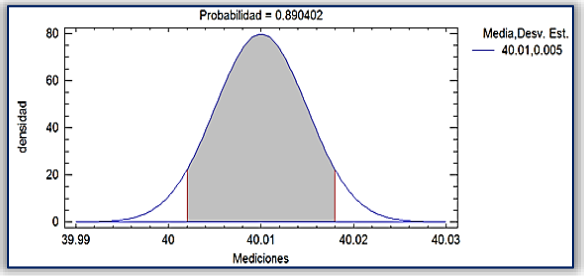

Figure 3. Graph of the dimensions´ values by design of the fixed trains haft. Own elaboration

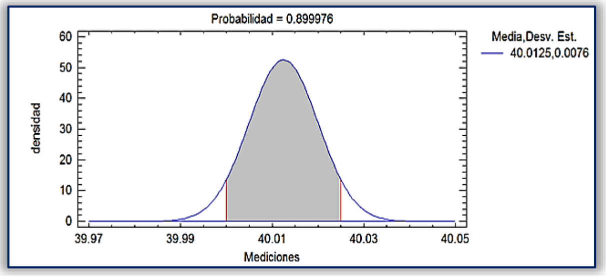

Figure 4. Graph of the dimensions´ values by design of the fixed train. Own elaboration

— Adjustment calculation: Ø40 H7/k6

In this case, both a maximum movement and a maximum fix were obtained, so the adjustment that exists between these two pieces is undetermined.

— Simulation calculations for the fixed trains haft

The sample size used is 50 measurements. The centering coefficient (K) is calculated obtaining as a result 0.00002mm. The process´ capacity index (Cp) is 1,337. Therefore, it can be said that the process is stable and the process´ critical capacity index (Cpk) is 1,333> 1,0 so that it is concluded that the process is capable.

— Simulation calculations for the fixed train hole

The centering coefficient (K) is calculated and results -0,00038mm. The process´ capacity index (Cp) is 1,338. Therefore, it can be said that the process is stable and the process´ critical capacity index (Cpk) is 1,297> 1,0 so that it is concluded that the process is capable.

Table 1.Results of the dimensions calculations. Own elaboration

	Dimensions (mm)	Design calculations Ø40 H7/k6(mm)	Simulation calculations Cp ≥1,33 y Cpk ≥1,0(mm)
Hole	$D_{máx}$	40,025	40,017
	$D_{mín}$	40,0	40,008
	D_{med}	40,0125	40,0125
	Tolerance	0,025	0,009
Shaft	$d_{máx}$	40,018	40,013
	$d_{mín}$	40,002	40,007
	d_{med}	40,01	40,01
	Tolerance	0,016	0,006
Fit	$J_{máx}$	0,023	0,01
	$Ap_{máx}$	0,018	0,005
	Tolerance	0,041	0,015

— **Results´ analysis**

1- It can be observed that when Cp≥1.33 and Cpk≥1.0, the dimensions are within the established range, so the process is capable and under control.

2- The maximum dimensions decrease and the minimum dimensions obtained from the simulation increase with respect to the dimensions obtained by design, so that the real tolerance range of each dimension decreases.

3- The adjustment will also decrease, obtaining a maximum movement and a maximum tightening less than results obtained by design.

3. ANALYSIS OF A MOBILE ADJUSTMENT

A measurements´ simulation of the drive shafts (shaft) and gears (hole) is made, with a setting Ø25 H7/h7.

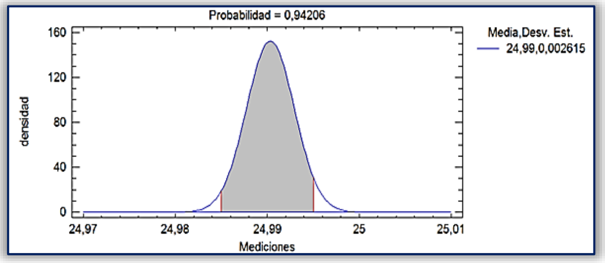

Figure 5. Graph of the simulated dimensions´ values of the drive shaft. Own elaboration

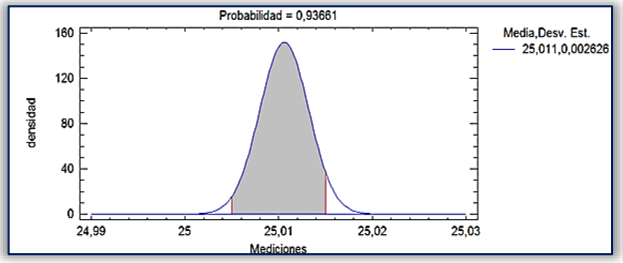

Figure 6. Graph of the simulated dimensions´ values of the gear. Own elaboration

— **Adjustment analysis Ø25 H8/h8**

In this case also a simulation of the measurements is carried out, the same diameter is maintained (Ø25) and the tolerance degree increased up to H8/h8, the capacity process´ coefficients are always restricted to greater than or equal to 1,33 and critical capacity of the process greater than or equal to 1,0 for the process to be capable and then a comparison is made with respect to the one analyzed above.

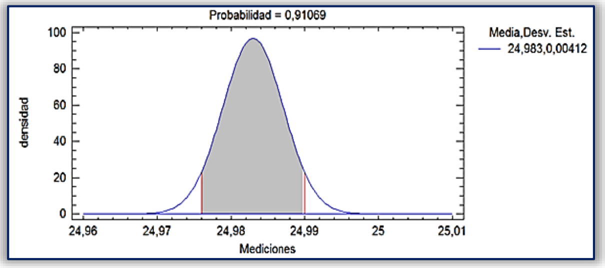

Figure 7. Graph of the simulated dimensions´ values of the drive shaft. Own elaboration

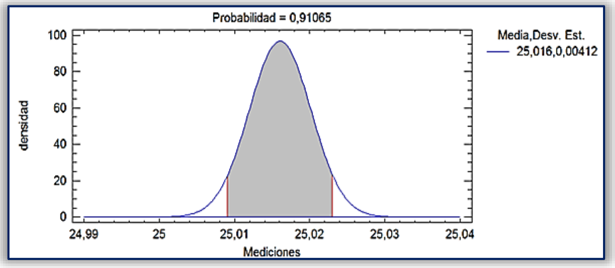

Figure 8. Graph of the simulated dimensions´ values of the gear. Own elaboration

A measurements´ simulation of the drive shafts (shaft) and gears (hole) is performed, with a setting of Ø25 H7/h7, these parts belong to the power supply of a match machine. To perform this analysis, Cp≥1,33 and Cpk≥1,0 are restricted for the process to be capable.

— **Design calculations for the drive shaft**

$$Ø25h7\binom{0}{-0{,}021}$$

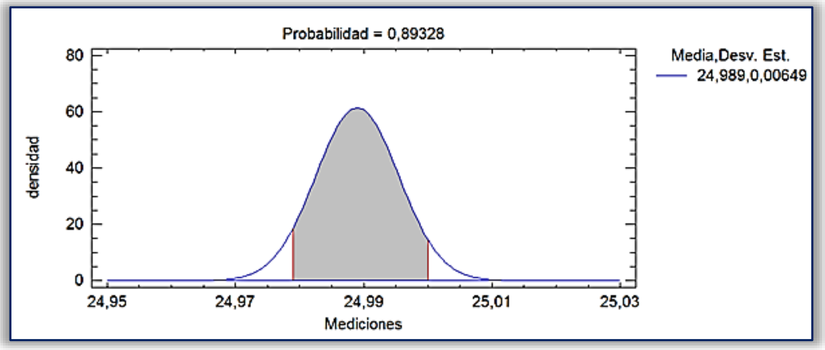

Figure 9. Graph of the dimensions´ values by design of the driving shaft. Own elaboration

— **Design calculations for the gear**

$$Ø25H7\binom{+\ 0{,}021}{0}$$

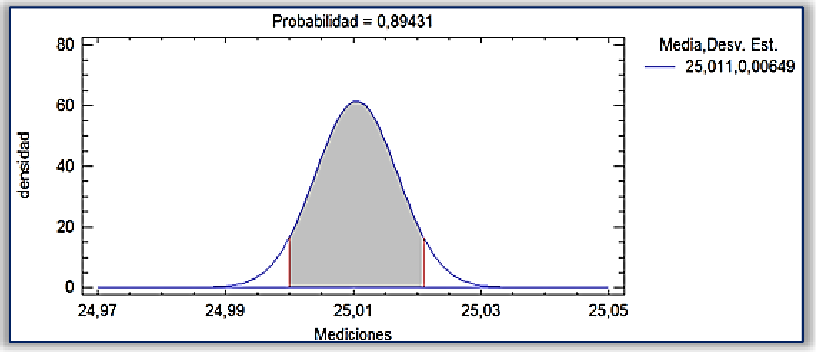

Figure 10. Graph of the dimensions´ values by gear design. Own elaboration

— **Adjustment calculation: Ø25 H7/h7**

In this case, a maximum movement and a minimum movement were obtained, so the fit that exists between these two pieces is mobile.

— **Calculations of the simulation for the drive shaft**

The sample size used is 50 measurements. The centering coefficient (K) is calculated and a value of -0,00034mm is obtained. The process´ capacity index (Cp) is 1,338. Therefore, it can be said that the process is stable and the process´ critical capacity (Cpk) 1,294> 1,0 so that it is concluded that the process is capable.

— **Simulation calculations for gear**

The centering coefficient (K) is calculated: and -0,0006mm is obtained. The process´ capacity index (Cp) is 1,332, therefore, it can be said that the process is stable and the process´ critical capacity of the Cpk = 1,255> 1,0, so the conclusion is reached that the process is capable.

— **Adjustment analysis for Ø25 H8/h8**

In this case also a simulation of the measurements is carried out, the same diameter (Ø25) is maintained and the tolerance degree is increased up to H8/h8, Cp≥1,33 and Cpk≥1,0 are always restricted so that the process be capable.

— **Design calculations for the drive shaft**

$$Ø25h8\begin{pmatrix} 0 \\ -0.033 \end{pmatrix}$$

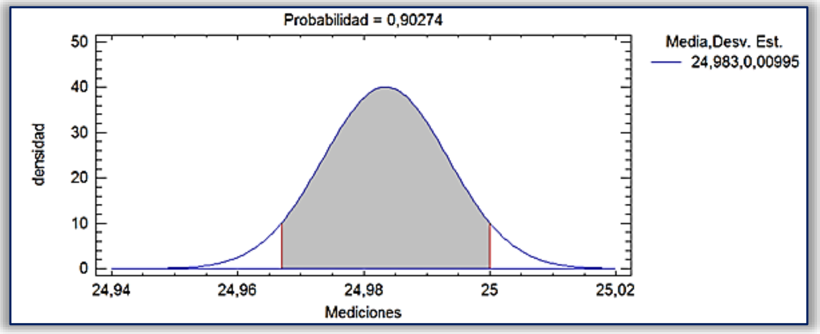

Figure 11. Graph of the dimensions´ values by design of the drive shaft. Own elaboration

— **Design calculations for the gear**

$$Ø25H8\begin{pmatrix} +\ 0,033 \\ 0 \end{pmatrix}$$

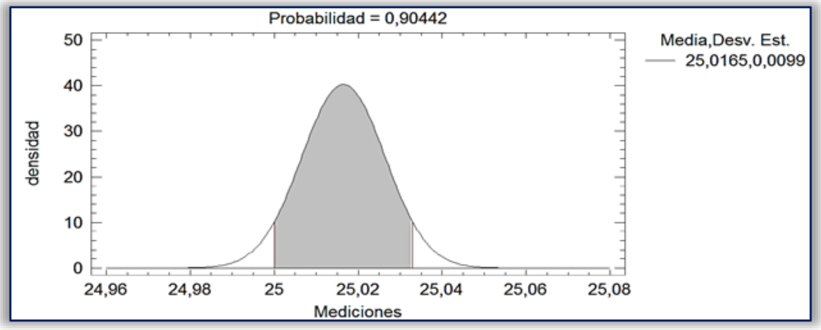

Figure 12 Graph of the dimensions´ values by design of the gear. Own elaboration

— **Adjustment calculation: Ø25 H8/h8**

— **Calculations of the drive shaft**

The centering coefficient (K) is calculated obtaining a value of -0,00018mm. The process´ capacity index (Cp) is 1,332, therefore, it can be said that the process is stable and the process´ critical capacity (Cpk) 1,317> 1,0 so that it is concluded that the process is capable.

— **Calculations of the gear**

The centering coefficient (K) is calculated by obtaining -0.00006mm. The process´ capacity index (Cp) is 1,334, therefore, it can be said that the process is stable and the process´ critical capacity (Cpk) 1,329>1,0 so it is concluded that the process is capable.

Table 2. Results of the dimensions calculations. Own elaboration

	Dimensions	Design calculations H7/h7	Simulation calculations H7/h7 Cp ≥1,33 y Cpk ≥1,0	Design calculations H8/h8	Simulation calculations H8/h8 Cp ≥1,33 y Cpk ≥1,0
Hole	$D_{máx}$	25,021	25,015	25,033	25,023
	$D_{mín}$	25,00	25,005	25,00	25,009
	D_{med}	25,0105	25,01	25,0165	25,016
	Tolerance	0,021	0,01	0,033	0,014
Shaft	$d_{máx}$	25,00	24,995	25,00	24,99
	$d_{mín}$	24,979	24,985	24,967	24,976
	d_{med}	24,9895	24,99	24,9835	24,983
	Tolerance	0,021	0,01	0,033	0,014
Fit	$J_{máx}$	0,042	0,03	0,066	0,047
	$J_{mín}$	0	0,01	0	0,019
	J_{med}	0,021	0,02	0,033	0,033
	Tolerance	0,042	0,02	0,066	0,028

— **Results´ analysis**

1- It can be seen that when Cp≥1,33 and Cpk≥1,0, the dimensions are within the established range, so the process is capable and under control.

2- The maximum dimensions decrease and the minimum dimensions obtained from the simulation increase with respect to the dimensions achieved by design, so that the real tolerance range of each dimension decreases.

3- The dimensions simulated with Ø25H8/h8 with respect to the dimensions of Ø25H7/h7 are quite similar, so it is concluded that it is effective to use the degree of tolerance 8 in the design of both pieces.

4. ANALYSIS OF A FIXED ADJUSTMENT

In this case, a measurements´ simulation of a bushing (shaft) and a pinion (hole) is performed, which have an adjustment Ø56H7/r6.

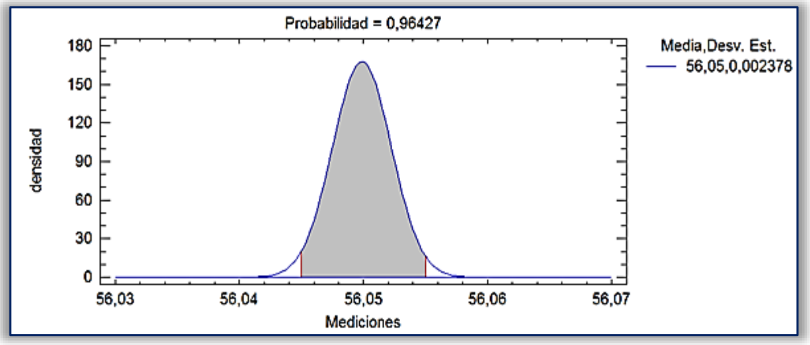

Figure 13. Graph of the simulated dimensions´ values of the bushing. Own elaboration

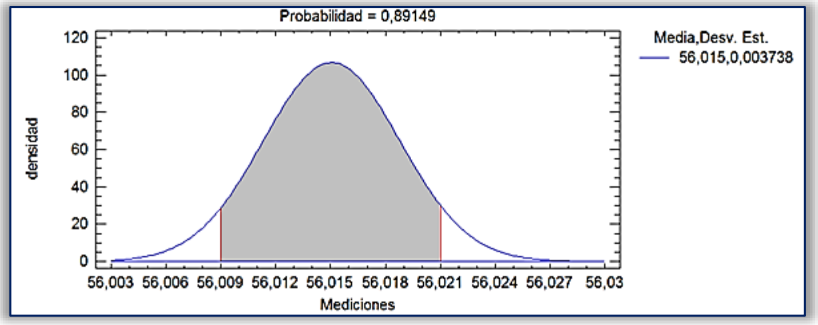

Figure 14. Graph of the simulated dimensions´ values of the pinion. Own elaboration

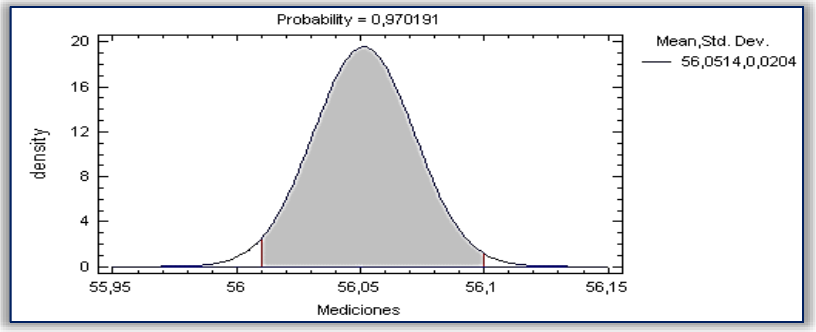

Figure 15. Graph of the dimensions´ values obtained of the bushing. Own elaboration

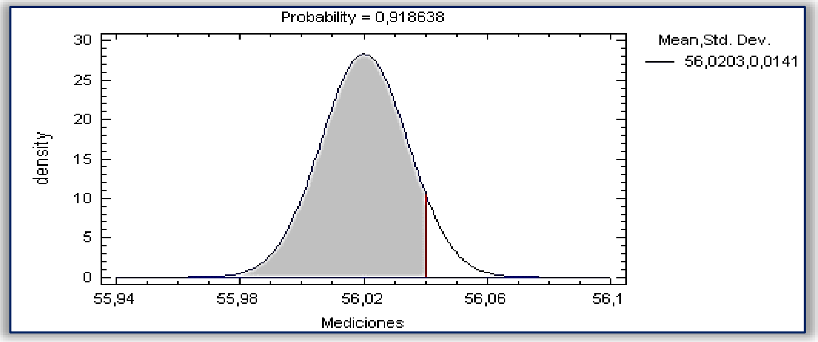

Figure 16 Graph the dimensions´ values obtained from the pinion. Own elaboration

In this case, a simulation of the measurements was made for of a bushing (shaft) and a pinion (hole) that belong to a Yung-6 tractor, which have an adjustment Ø56 H7/r6. As in the previous cases, Cp≥1,33 and Cpk≥1,0 are restricted for the process to be capable.

— **Design calculations for the bushing**

$$Ø56r6\binom{+\ 0,060}{+\ 0,041}$$

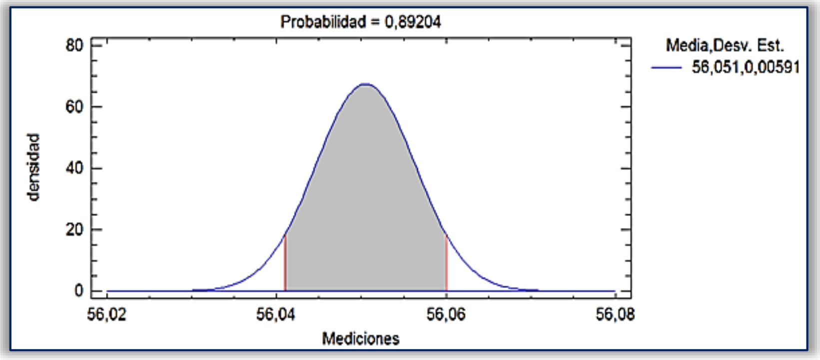

Figure 17. Graph of the dimensions´ values by design of the bushing. Own elaboration

— **Design calculations for the pinion**

$$Ø56H7\binom{+\ 0,030}{0}$$

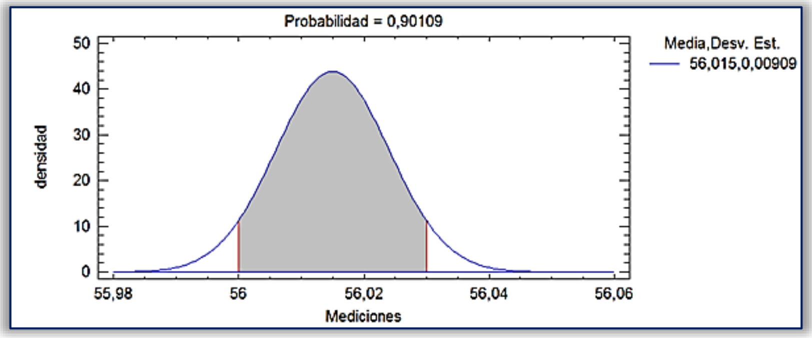

Figure 18. Graph of the dimensions´ values by design of the pinion. Own elaboration

— **Adjustment calculation**

Ø56 H7/r6

From the following equations we obtain that:

$$Ap_{máx} = d_{máx} - D_{mín} = e_s - E_i = 0{,}060 - 0 = 0{,}06 \text{ mm}$$

$$Ap_{mín} = d_{mín} - D_{máx} = e_i - E_s = 0{,}041 - 0{,}030 = 0{,}011 \text{ mm}$$

$$T = Ap_{máx} - Ap_{mín} = T_{agujero} + T_{eje} = 0{,}06 - 0{,}011 = 0{,}049 \text{ mm}$$

— **Bushing simulation calculations**

The sample size used 50 measurements for each case. The centering coefficient (K) is calculated by obtaining a value of 0,00012mm. The process´ capacity index (Cp) is 1,331, therefore, it can be said that the process is stable and the process´ critical capacity (Cpk) 1,314>1,0 so it is concluded that the process is capable.

— **Calculations of the simulation for the pinion**

The centering coefficient (K) is calculated obtaining a value of -0.00006mm. The process´ capacity index (Cp) is 1,337, therefore, it can be said that the process is stable and the process´ critical capacity (Cpk) 1,331>1,0 so that it is concluded that the process is capable.

— **Simulation adjustment calculation**

$$Ap_{máx} = d_{máx} - D_{mín} = e_s - E_i = 0{,}055 - 0{,}009 = 0{,}046 \text{ mm}$$

$$Ap_{mín} = d_{mín} - D_{máx} = e_i - E_s = 0{,}045 - 0{,}021 = 0{,}024 \text{ mm}$$

$$T = Ap_{máx} - Ap_{mín} = T_{agujero} + T_{eje} = 0{,}06 - 0{,}011 = 0{,}022 \text{ mm}$$

Table 3. Results of the dimensions calculations. Own elaboration

	Dimensions	Design calculations H7/r6	Simulation calculations H7/r6 Cp ≥1.33 y Cpk ≥1.0
Hole	$D_{máx}$	56,03	56,021
	$D_{mín}$	56,00	56,009
	D_{med}	56,015	56,015
	Tolerance	0,03	0,012
Shaft	$d_{máx}$	56,06	56,055
	$d_{mín}$	56,041	56,045
	d_{med}	56,0505	56,05
	Tolerance	0,019	0,01
Fit	$Ap_{máx}$	0,06	0,046
	$Ap_{mín}$	0,011	0,024
	Tolerance	0,049	0,022

— **Results analysis**

1- It can be seen that when Cp ≥ 1,33 and Cpk ≥ 1,0, the dimensions are within the established range, so the process is capable and under control.

2- The maximum dimensions decrease and the minimum dimensions obtained from the simulation increase with respect to the dimensions obtained by design, so that the real tolerance range of each dimension decreases.

5. CONCLUSIONS

The individual tolerance must be assigned according to the fit´s process´ capacity index, since this is greater than the tolerance of the hole and the shaft separately, due to its probabilistic origin; in this case, the conjugation of two smooth cylindrical pieces joined together that form a movement and/or tighten. The above constitutes a novel contribution of the investigation because it allowed the introduction of the coupling´s capacity index in the adjustment.

In the tolerance analysis influence the individual tolerances of each piece, the sequence and methods of assembly in the set; in addition, in some sets, the operating and assembly conditions depend not only on the dimensions and settings assigned, but also on the size and variation of other physical quantities.

The pieces can be raised to a degree of tolerance (IT) according to the described calculations; in the case of mobile fit it is advantageous as long as the process is capable because the results show that both dimensions are similar.

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