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Research article

Tolerance analysis (static and dynamic) of the gearbox assembly to achieve correct manufacturing tolerances

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Abstract

Tolerance analysis is one of the most important parameters affecting the quality and production costs of a product. In this research, using the tolerance analysis capabilities in Inventor software to set the tolerance of the speed reducer gearbox. First, the dimensions of the conical rotor of the elevator gearbox were obtained by Geomagic reverse engineering software, and then the results were used in Inventor software to develop the gearbox model into a three-speed gearbox. Dimensional and geometric static tolerance analysis of this collection was done by using the worst-case, sum of square roots, process capability index and sigma methods. The results showed the worst-case method in tolerance analysis works more cautiously than other methods, as well as the residual sum of squares method, shows less laxity and interference than the worst-case method. Process index method, confirmed the assembly and in the sigma method, the sigma function considers the level of tolerance to be acceptable. Also, to ensure the correctness of the obtained tolerances, dynamic analysis has been done by using ADAMS software. The results showed that the set did not have any excessive slack or interference during movement. For validation, the results of this study were compared with Monte Carlo simulation results and showed good agreement.

Keywords: Static tolerance analysis, Dynamic tolerance analysis, Dimensional tolerance, Geometric tolerance, Inventor software

1- Introduction

Along with the rapid development of technology, the need for accurate production of parts used in advanced industrial equipment is increasing day by day it is spread [1]. On the other hand, the precise manufacturing of industrial parts with complex geometries is completely dependent on precise design and manufacturing [2,3]. Hence in order to produce higher quality products and lower production time and cost, many new concepts such as design for manufacturing, design for assembly and simultaneous engineering have been recommended by scientific and industrial societies [4]. The main idea behind these concepts is to examine manufacturing issues at the time of product design. In other words, it is possible to coordinate the design process with subsequent processes (manufacturing and assembly) [5,6]. The most important parameters that play an important role in creating this coordination are measurement and geometric tolerances [7, 8]. Making a piece completely without deviation from the original dimensions approx. It's impossible. Therefore, in the design phase, the amount of permissible deviations from the nominal dimensions and the amount of geometrical changes of the parts should be considered[9,10,11]. Walter and et al. reviewed the analysis of tolerance and a survey was conducted on the awareness and usage of tolerance analysis in German industries. The author showed that geometric tolerance analysis is very important to increase the functional quality of products[12]. Omaras et al analyzed the tolerance based on Monte Carlo simulation to optimize the design of the car water pump. They presented a model of integrated design and manufacturing that both saves cost and improves reliability [13]. Palini et al. reviewed tolerance analysis from a static point of view. According to the author, industrial requirements for designing high-quality products in shorter times lead to the use of numerical models. Numerical models reduce time to market and design costs. The writer presented a static model for tolerance analysis, which is done by algebraic or graphical methods using free body diagrams. This model could use dimensional and geometric tolerances. In addition, this model for analysis the tolerance of rigid parts was used and the results confirmed the numerical and experimental compatibility of the model [14]. Tolerance analysis of gear trains by static analogy was done by Armillotta. He shows that assembly-level geometric errors such as backlash, center distance errors and shaft misalignments may adversely affect the operation of a gear train. The tolerance analysis method proposed in this paper estimates these errors from tolerance specifications on gears and mounting parts (shafts, bearings, housings) [15]. Wisniewski and Gomer demonstrated the use of an advanced 3-D tolerance analysis simulation technique to determine three quality characteristics of engines. They describe the use of VSA-iD® to statistically predict engine balance, valve overlap volume, and front-end accessory drive belt and pulley alignment[16]. Based on a unified Jacobian-Torsor model, a statistical method of distinguishing and quantifying tolerances in assemblies was presented by Chen et al. The internal relation of tolerances inside a combinational tolerance was established by data fitting methods, and a calculating scheme used for percent contributions and their subdivisions was proposed[17]. A review on tolerance analysis approaches in mechanical assemblies was done by Amda et al. the focus of their research is on tolerance analysis approaches in product design and optimization tools used on various models[18]. A new tolerance analysis approach is developed based on the univariate DRM and Pearson system concepts by Hasani and Khodaygan. The proposed method can analyze directly without the need to define any assembly function and also the rejected product rate can be easily predicted using evaluations of the assembly dimension at the limited number of special points [19]. In this research, for the first time, the static and dynamic tolerance analysis of the gearbox has been done using Inventor and ADAMS software to achieve correct manufacturing tolerances. Also, by using different methods, the tolerance analysis of the assembly was performed simultaneously and the results were compared with each other.

2- Description of the problem

In this research, first by using Geo Magic reverse engineering software, the dimensions of the bevel gear of the elevator gearbox (Figure 1) are obtained and then tolerance analysis is done on it by using the inverter analysis software. In order to validate the tolerance analysis of the studied gear, Monte Carlo method has also been performed and the results have been compared with the results of the inverter software (Table 1). As can be seen, the results of the software have acceptable accuracy.

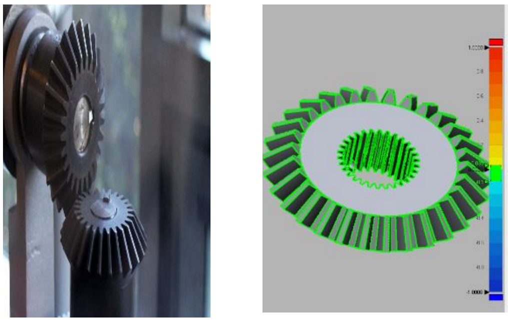
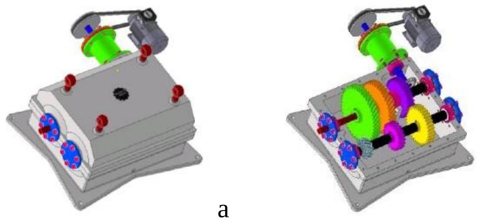


Fig. 1 Conical rotor of the elevator gearbox
a) Real b) Modeling in GeoMagic software

Table 1: Comparison of the results of the present study with the results of the Monte Carlo method

Tolerance obtained by Monte Carlo method	Acquired tolerance current) (research	Sizes given
95º ±10´	95º ±12´	The outer angle of the gear
84º ±10´	84º ±15´	Internal angle of the gear wheel
53.2±0.05mm	53.2±0.1mm	Large outer diameter
48.1±0.05mm	48.12±0.1mm	small inner diameter

In the following, with the development of the gearbox model to a three-speed gearbox, dimensional and geometrical static tolerance analysis has been done using Inverter software. The simulated model includes an adaptive sliding gear type speed reducer and will be able to provide 1:2, 1:1 and 1:3 speed ratios and includes 191 standard parts. Fig. 2 shows the designed gearbox.



a b

Fig. 2 Modeled gearbox a) with upper body b) without upper body

The speed ratio is changed according to the number of teeth of each gear and at 1:1 speed through two bevel gears with the number of teeth is 43 in the gearbox, and the teeth of the input shaft of the gearbox are connected to the output shaft and transfer the power to the outside. The gearbox transfers. In speed 2: 1, two gears with 38 and 19 teeth transmit power. in this case the connection between the input and output shafts is cut off, and after entering the shaft, the power is connected to the gear with 19 gears and through that gear. It rotates the 38 teeth mounted on the output shaft and reduces the speed ratio to create a speed of 1:3. the same operation will be done with the number of teeth 14 and 43. Next, the tolerances placed on each individual axis of the item tolerance analysis will be included. It should be noted that in the current model there are six gears (three contact points) and in different positions they engage with each other to create different speed ratios in the vertical direction (Fig.3). In this case, considering the distance in two axes, the tolerance of one part is positive and the opposite part is negative to prevent the accumulation of tolerance.

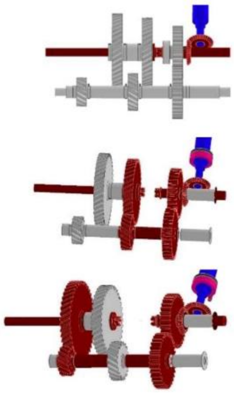


Fig. 3 Creation of different speed ratios by the studied gearbox (Speed from image top to bottom in order: 1:1, 2:1, 3:1)

It should be noted that all parts are modeled using drawing commands and using the in-program plugin of Inventor software. Static tolerance analysis and then dynamic tolerance analysis using Adams software to avoid interference during operation possible to appear.

2-1-Static analysis

In the analysis of mechanical systems, especially in rotating systems, before ensuring the use and fulfillment of the requirements of the case comment in the dynamic state in the presence of forces, it is necessary to check the static state. In static analysis, the main goal is to check the correctness and guaranteeing the quality of the component performance and performing the assembly function in the idle state of the machine in different conditions. In static analysis, characteristic the subject of investigation is usually the deviations related to the axis of rotation, which there are several dimensional methods for its analysis, which are described below. Dimensional static analysis methods used in this research are introduced in addition to the static analysis done in this research, in addition to dimensional tolerances, given geometrical tolerances have been checked and optimal tolerance values have been presented.

2-2-Worst case method

This method can be called one of the most common methods of accumulation analysis. The reason for naming as "worst case", the reason for this method is based on this (worst case). This is the action that all the dimensions of the set simultaneously in the largest or it rarely happens that they are the smallest allowed size [20]. Usually in situations where the set has a critical design requirement of the interference type and the number of set pieces or the number of required effective dimensions the design is low; the worst-case method is used. In the case of using this method to analyze non-linear problems, only from the first term approximation of the Taylor expansion is used and the high order terms are removed. Accumulation of tolerance in worst case analysis it is calculated using (1).

$$Tol_{RC} = \left|\frac{\partial_{RC}}{\partial_b}\right| Tol_b + \left|\frac{\partial_{RC}}{\partial_c}\right| Tol_c + \left|\frac{\partial_{RC}}{\partial_d}\right| \mathrm{Tol}_d + \left|\frac{\partial_{RC}}{\partial_e}\right| \mathrm{Tol}_e + \left|\frac{\partial_{RC}}{\partial_\theta}\right| \mathrm{Tol}_\theta + \left|\frac{\partial_{RC}}{\partial_\alpha}\right| T_{ol\alpha} \quad (1)$$

In most cases, analyzed tolerances are asymmetrical, geometric tolerances need interpretation in most cases, and this method is due to its simplicity and performance guarantees are widely used.

2-3-The residual sum of squares method (RSS)

This method can be called one of the most famous tolerance accumulation analysis methods that many people use. This statistical method it is based on this that the probability of the dimensions of the parts being on the edges of the tolerance range is very low. In analyzes that function the design is a non-linear function, the non-linear function can be linearized by Taylor expansion without paying attention to the high-order terms, which gives accurate results. also provides in this statistical analysis, the distribution of changes in the output is normal, provided that the design function is linear and the distribution of changes the input is also normal[21]. Tolerance chain in this method is obtained by using (2):

$$ToI_{RC} = \sqrt{\left(\left|\frac{\partial_{RC}}{\partial_b}\right| ToI_b\right)^2 + \left(\left|\frac{\partial_{RC}}{\partial_c}\right| Tol_c\right)^2 + \left(\left|\frac{\partial_{RC}}{\partial_d}\right| Tol_d\right)^2 + \left(\left|\frac{\partial_{RC}}{\partial_e}\right| Tol_e\right)^2 + \left(\left|\frac{\partial_{RC}}{\partial_\theta}\right| Tol_\theta\right)^2 + \left(\left|\frac{\partial_{RC}}{\partial_\alpha}\right| Tol_\alpha\right)^2} \quad (2)$$

2-4-Sigma method

"Sigma" is one of the important indicators of dispersion and a scale for measuring standard deviation. This indicator shows that a process to what extent has it deviated from its normal and desirable state. Sigma, the importance of accurate calculations in the process of production and service delivery emphasizes and will be able to obtain the tolerance. Equation 3 is the calculation formula in the Sigma method:

$$\sigma = \sqrt{\sum_{i=1}^{N} p_i (x_i - \mu)^2}, \mu = \sum_{i=1}^{N} p_i x_i \quad (3)$$

2-5-Capability process index method (CPK)

When the position of the trend is studied in relation to the tolerance limits, the capability process index method is used to identify process characteristics for the situation. A high capability process index means you have a good process with a you have a small expansion in relation to the tolerance width and also place it in the width of this axis. If the process capability is equal to Cp, the process is placed exactly in the middle of the tolerance range. The capability process index method is obtained from (4):

$$Cpk = min[(USL-mean)/3\sigma, (mean-LSL)/3\sigma] \quad (4)$$

In the above relationship, σ is the standard deviation, USL is the upper limit of the specification and LSL is the lower limit of the specification.

2-6-Dynamic analysis

In dynamic tolerance analysis, the performance of the assembly compared to the mechanical assembly, especially in rotating assemblies, has a lot of variation. Usually, assembly functions in static mode can be called target functions and assembly functions in dynamic mode, but on the contrary not true for example, if a position is considered in static mode, the same goal can be achieved for dynamic mode as well defined. It should be noted that the assembly performance of a target is different in static and dynamic mode. In the dynamic mode of agents related to speed and acceleration appear directly or indirectly in the assembly operation. Therefore, the studied objectives in the state dynamic must be specified and for each purpose, the assembly function must be determined and extracted in terms of translational and rotational degrees of freedom. Dynamic analysis of rotating mechanical system can be done in different ways, the first goal in rotating mechanical system deviation from the nominal position of the rotating part of the assembly at different points. Investigating support forces as a result of system dynamics and inertia and effective damping forces are other important factors that affect the choice of bearings. In this research, in order to ensure the absence of the interference of the investigated gearbox during movement, dynamic analysis has been done using ADAMS software. The rotation speed of the input axis of this set is 10,000 revolutions per second and the dimensions of the parts are considered as maximum and minimum.

ADAMS is a multibody dynamics simulation software system that simulates the behavior of the system over time and can animate its motion and compute properties such as accelerations, forces, etc. The system can include further complicated dynamic elements like springs, friction, flexible bodies, contact between bodies. The software also provides extra CAE tools such as design exploration and optimization based on selected parameters

3-Results and discussions

The optimal results of dimensional tolerance analysis of the main axis the studied gearbox set includes 4 sections, the power input axis, the main axis, the interface axis and the output axis for each axis tolerance analysis has been done separately and the optimal results have been presented in different formats. In this section, the results obtained from worst-case methods, sum of square roots and statistical methods that measure statistical results in the form of process capability index, method sigma, are reportable for the main axis, using which a complete report of parts tolerance with a visual display is created. The main axis which is directly rotated by the bevel gear which is engaged with the input axis it is 134 mm and includes cover, casing, bearing, shim, spacer, bevel gear and spiral gear. It is the main axis. The graphic view of the main axis with the nominal size and also the permissible distance between them in the assembled assembly Fig.4 is. In this figure, the total length of the axis is 134 millimeters and the rest of the parts separately along with the length of the parts and the allowed distance shown between them. Dimensional static analysis has been done using different methods described for the main axis and the results are presented below.

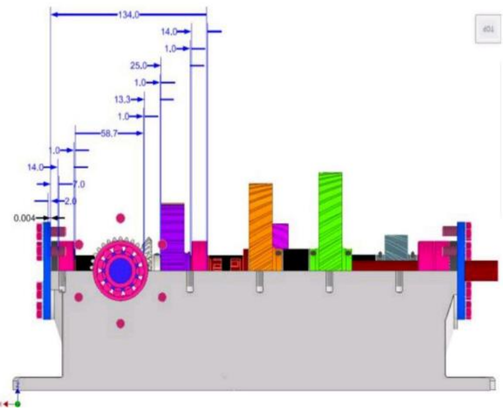


Fig. 4 Nominal dimensions and permissible distance of the main axis of the gearbox assembly

In the worst-case method, the accumulation analysis along the whole axis showed that the main axis does not interfere after construction. Using the plugin tolerance analysis and correction of the performed tolerances, the results of the worst case were close to zero and the graph was in the green state(Fig. 5). which shows the quality of tolerance:

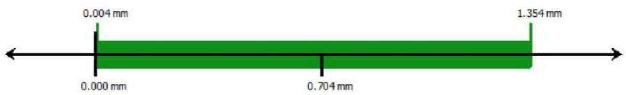


Fig. 5 Worst case software tolerance diagram for the main axis

Also, the results obtained from the root sum of square analysis method show the tolerance range of the main axis in its optimal and positive state It says that the parts are well assembled after manufacturing and there is no error. The graph of the obtained sum of square roots it is shown for the main axis in Fig. 6.

The tolerance analysis of the main axis has also been done using the process capability index method (Fig. 7). It shows the software tolerance for the main axis, as can be seen, the obtained process capability index number is 3.22, which is an acceptable value compared to the value (1/52, the minimum acceptable in this method).

The objective function of the process capability index: (1.53 at least)

The obtained process capability index function: 3.2

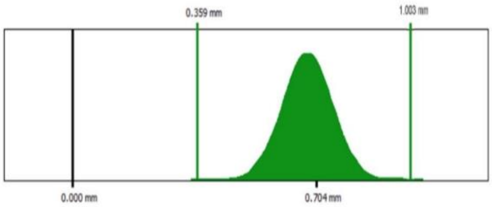


Fig. 6 Software tolerance process capability index diagram for the main axis

The analysis by sigma method showed that the quality of tolerancing is very favorable and by using this tolerancing, the number can be Sigma 6.41 was obtained and considering that the number is higher than the acceptable limit of 5, this graph is also the quality of tolerance. confirmed what was done.

Sigma objective function: (minimum 4.56)

Obtained sigma function: 6

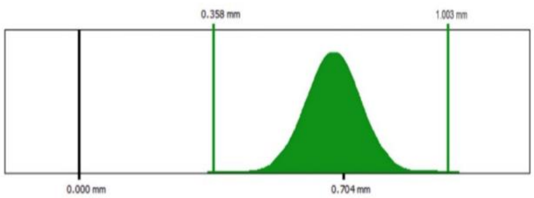


Fig. 7 Software tolerance sigma diagram for the main axis

The optimal results of dimensional tolerance analysis of the main axis are presented in Table 2

Table 2: The optimal results of dimensional tolerance analysis of the main axis

	optimal
Worst case results	All tolerances are acceptable
The results of the sum of square roots	All tolerances are acceptable
Process capability index results	3.22>1.53 acceptable
Sigma results	6.41>5 acceptable

3-1-The results of geometric tolerance analysis of the main axis

In this research, in addition to dimensional tolerancing, the given geometrical tolerances were checked and the optimal tolerance values were presented. It should be noted that all types of geometric tolerances can be considered for each level, but because the cost of manufacturing the part it goes up a lot. The tolerances that are needed for the set to work properly are laid out in the parts map and the software. Inventor checks the tolerances in the map. For the main axis, the dimensional tolerances are placed in Figures 8 to 12 and the results of software analysis to optimize these tolerances are presented in Table 3 for comparison.

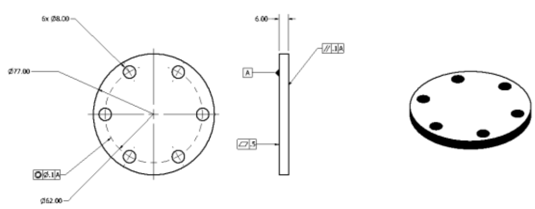


Fig. 8 Cover on the body of the gearbox assembly

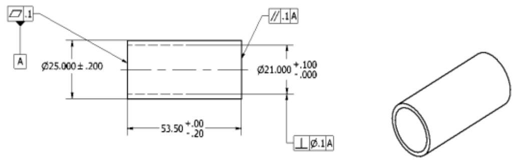


Fig. 9 The distance between the shim and the gear of the main axis of the set

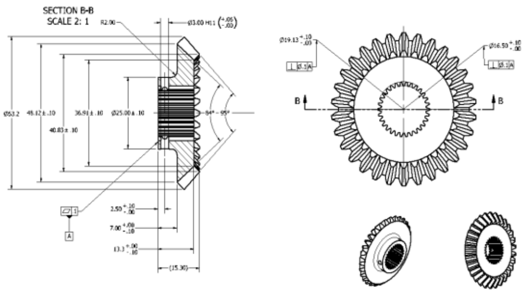


Fig. 10 Conical rotor of the main axis of the set

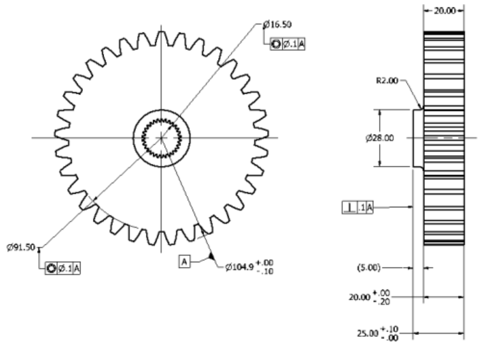


Fig. 11 The simple rotary of the main axis of the gearbox assembly

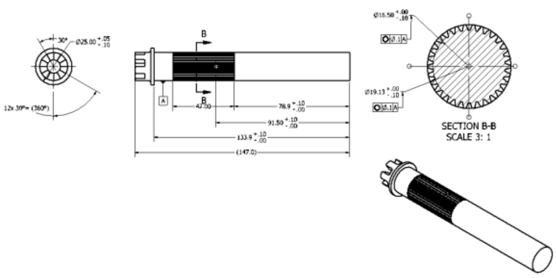


Fig. 12 The main axis of the gearbox assembly

3-2- Optimal results of dimensional tolerance analysis of the input axis

In this part, the results of the tolerance analysis for the input axis are given, the results of the tolerance analysis of this axis show that in the test in the worst case, there is only 0.1 mm of interference and the results of the sum of square root, process capability index and sigma analysis methods are also close to software solutions.

Table 3: The optimal results of geometric tolerance analysis of the main axis

Tolerance value	The tolerance are set	piece
0.02	A bed	**Cover**
0.06	Co central	
0.05	Parallel	
0.08	Parallel	**Spacer**
0.03	A bed	
0.04	Orthogo	
0.04	A bed	**Bevel gear**
0.08	Orthogo	
0.08	Orthogo	
0.09	Co central	**Simple gear**
0.09	Co central	
0.01	Orthogo	
0.05	Co central	**Mail axis**
0.06	Co central	

Therefore, the tolerance of this axis compared to the main axis of the gearbox set is of quality has a higher Table 4 presents the optimal results of dimensional tolerance analysis of the input axis.

Table 4: Optimal results of dimensional tolerance analysis of the input axis

Optimal	
All tolerances are acceptable	Worse case results
All tolerances are acceptable	The results of the sum of the square roots
Acceptable 1.67> 1.63	The results of the process capability index
(Acceptable) 5.01 >5	Sigma results

3-3-Optimal results of geometric tolerance analysis of the input axis

In this axis, like the main axis of the collection, it was subjected to the geometric tolerance analysis test. The construction parts of this axis with the performed tolerances can be seen in Figs. 13 and 14 and the results in Table 5.

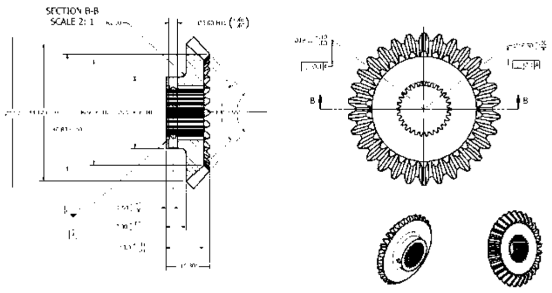


Fig. 13 Bevel gear of gearbox set

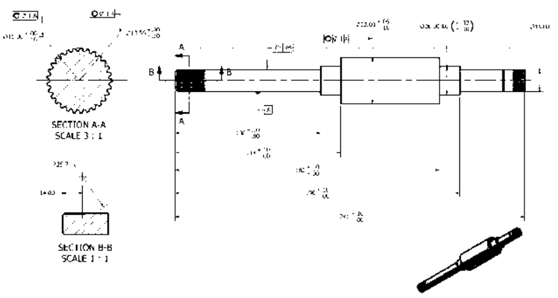


Figure 14. The main entrance axis

Table 5: Optimum results of geometric tolerance analysis of the input axis

Tolerance value(mm)	**The tolerances are set**	**Piece**
optimal		
0.02	Cylindrical	**Main axis**
0.05	Co-central	
0.04	Co-central	
0.06	Co-central	
0.04	Like a bed	**Bevel gear**
0.06	orthogonal	
0.07	orthogonal	

3-4-Optimal results of dimensional tolerance analysis of the interface

This axis is the longest axis of the assembly set and it is 350 mm long and it adjusts the connection between the input and output axis. And it plays an essential role in reducing the speed. This axis includes two helical gears and one simple gear with the input axis are involved This axis is not involved with the output axis while creating a speed of 1:1, and while creating a speed of 2:1, the middle spiral rotor and while creating a speed of 3:1, the left spiral rotor engages with the output shaft. Table 6 shows the optimal results of the dimensional tolerance analysis of the interface axis. As can be seen, all the methods accept tolerance for the axis of the interface.

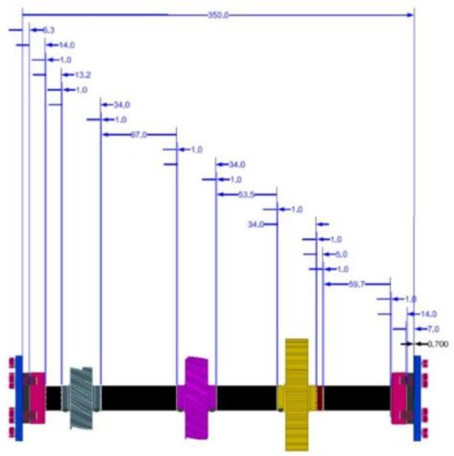


Fig. 15. Showing the axis of the interface along with accessories and nominal dimensions

Table 6: Optimal results of dimensional tolerance analysis of interface axis

	optimal
Worst case results	All tolerances are acceptable
The results of the sum of square roots	All tolerances are acceptable
Process capability index results	4.42>1.63 acceptable
Sigma results	6.41>5 acceptable

3-5-Optimum results of geometric tolerance analysis of the interface axis

The interface axis includes 4 spacers, 2 spiral gears and one simple gear. A map of the components of the interface along with the tolerances placed in Figures 16 to 23 and the results of geometric tolerance analysis are also presented in Table 7.

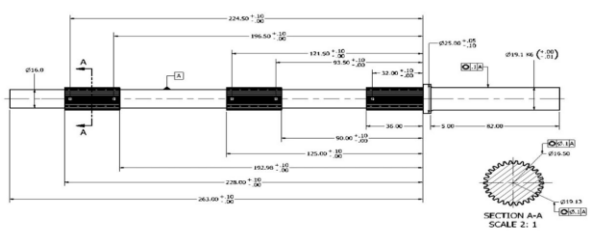


Fig. 16 The main axis of the interface

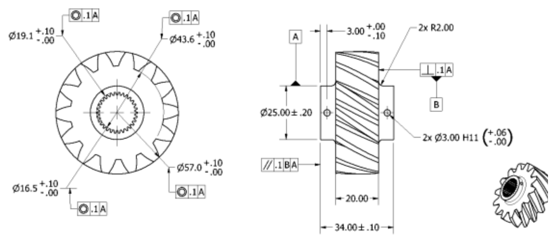


Fig. 17 Small helical gear of interface axis

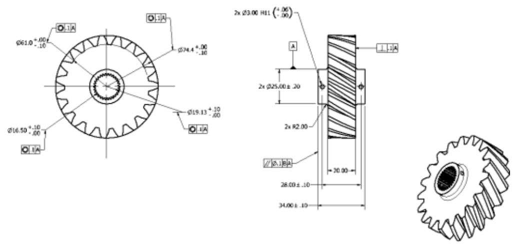


Fig. 18 The big spiral gear of the interface axis

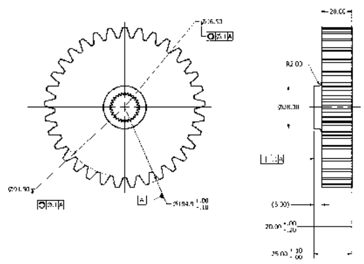


Fig. 19 Simple interface axis gear

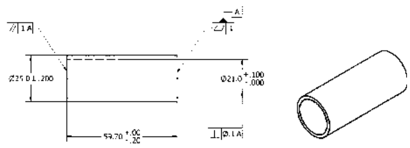


Fig. 20 Distance gauge 1 interface axis

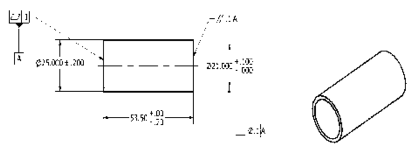


Fig. 21 Distance meter of 2 interface axis

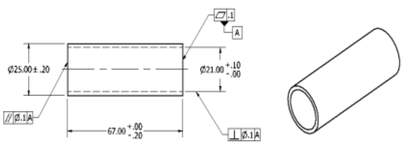


Fig. 22 distance meter of 3 axes of the interface

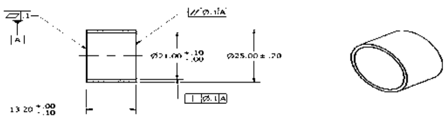


Fig. 23 Distance gauge of 4 axes of the interface

Table 7: Optimum results of geometric tolerance analysis of the interface axis

Tolerance	Tolerance laid done	Piece	tolerance	The tolerances are set	Piece
0.03	Orthogonal	Distance guage 59.70 mm	0,04	Co central	Main axis
0.04	parallel		0,04	Co central	
0.04	A bed		0,04	Co central	
0.03	Orthogonal	53.5	0,03	Orthogonal	Small bevel gear
0.04	parallel		0,04	parallel	
0.03	A bed		0,06	Co central	
0.04	Orthogonal	67mm	0,06	Co central	
0.05	parallel		0,03	central	
0.04	A bed		0,03	central	
0.04	Orthogonal	13.2 mm	0,04	Orthogonal	Large bevel gear
0.03	parallel		0,04	caress	
0.04	A bed		0,05	Co central	
0.03	Orthogonal	Simple gear	0,05	Co central	
0.04	Central		0,03	central	
0.04	Central		0,03	central	

3-6-Optimal results of dimensional tolerance analysis of the output axis

This axis is the second longest axis of the assembly set and it is 185.2 mm long and has two helical gears along with gears. The interface sets the output speed. This axis receives the power directly from the input axis while creating 1:1 speed and communication it is cut with the axis of the interface. The assembled set of this axis alone is shown in Fig. 24.

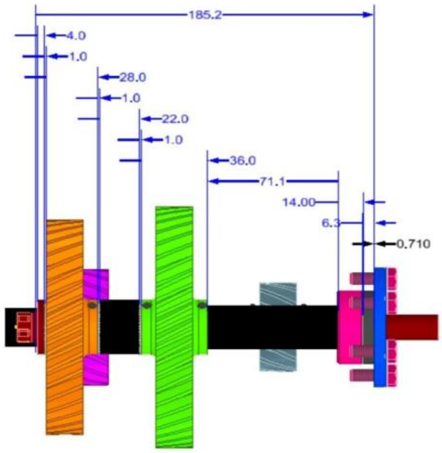


Fig. 24 Display of the output shaft along with accessories and nominal dimensions

Table 8 shows the optimal results of the dimensional tolerance analysis of the output axis, as can be seen from the worst-case methods. and the sum of the square roots of all tolerances are considered acceptable, and the results of process capability and sigma method are equal to 3.19 and it is 6.41, which is higher than the acceptable minimum, so all 4 tolerance methods are considered favorable.

Table. 8: Optimal results of dimensional tolerance analysis of the output axis

	optimal
Worst case results	All tolerances are acceptable
The results of the sum of square roots	All tolerances are acceptable
Process capability index results	3.19>1.63 acceptable
Sigma results	6.41>5 acceptable

3-7-Optimal results of the geometric tolerance analysis of the output axis

This axis consists of two bevel gears, two spacers and the main axis. Map of parts of this axis in Figs. 25 to 29 and the comparison of the results is presented in Table 9.

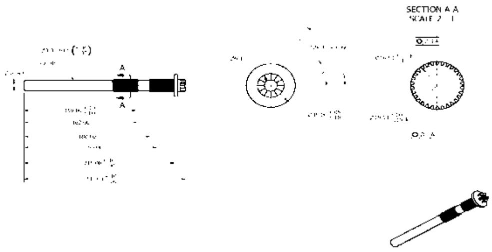


Fig. 25 Main output axis

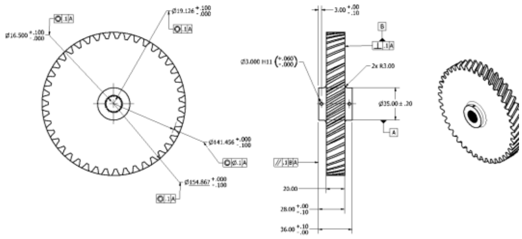


Fig. 26 Large spiral gear of the output shaft

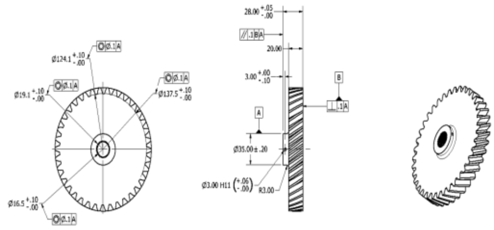


Fig. 27 Small helical gear of the output shaft

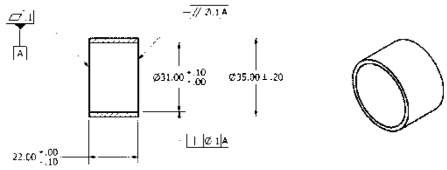


Fig. 28 distance measurer 1 output axis

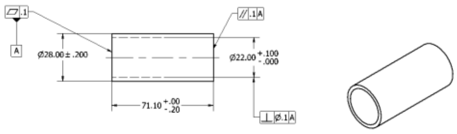


Fig. 29 distance measurer 2 output axis

3-8-Dynamic analysis of gearbox assembly

In order to ensure the absence of interference of the studied gearbox set while moving, using Adams software, this set of analysis it has become dynamic. The rotation speed of the input axis of this set is equal to 10,000 revolutions per second or 10 degrees of rotation per millisecond is considered and in order to check the performance of the set, once the dimensions of the parts are considered as maximum and another time as minimum and in both cases, the result of the dynamic analysis of the set showed that the set has no excessive slack during movement or there is no interference and its performance during rotation and after construction will be favorable. The output graphs of force output are shown in figure 30 and 31, as seen in the contact points of the gears to each other during the analysis time, which is considered equal to 100 milliseconds, no additional force occurs during the rotation of the axes does not come and the force continues linearly until the end, which shows that the parts do not interfere with each other and create additional force during the analysis will be. It should be noted that at first, due to the initial impact of the gears, Total force increases, but during time it decreases

Table 9: Optimum results of geometric tolerance analysis of the output axis

Tolerance value	Tolerances placed	piece	Tolerance value	Tolerances set done	Piece
0.04	parallel	Large bevel gear	0.05	cylindrical	Main axis
0.04	orthogonal		0.04	Co central	
0.05	Co central		0.04	Co central	
0.05	Co central		0.04	orthogonal	Small bevel gear
0.04	Co central		0.03	Parallel	
0.04	Central		0.05	Co central	
0.03	orthogonal	Distance guage 71.1mm	0.05	Co central	
0.03	parallel		0.04	Central	
0.04	A bed		0.04	Central	
			0.03	Orthogonal	Distance gauge 22mm
			0.05	Parallel	
			0.03	A bed	

rapidly. In Fig. 32, the Total force is shown with a magnification of 10 milliseconds at the beginning of the engagement of the gears, which decreases significantly during the process of applying force in the gears to each other.

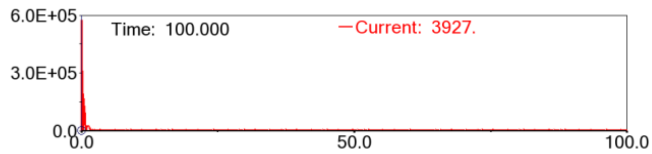


Fig. 30 Total force at the point of contact of two simple gears

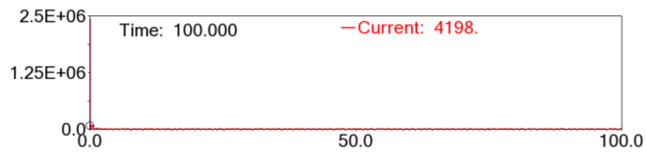


Fig. 31 Total force at the point of contact of two spiral gears to create speed 1:2

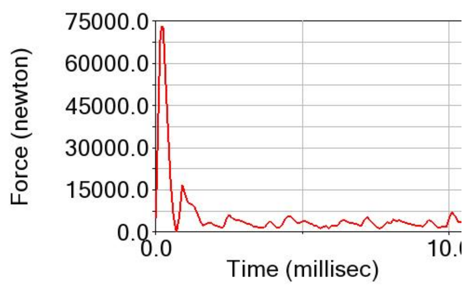


Fig. 32 The total force at the point of contact of two helical gears to create a speed of 1:2

4-Conclusion

In this research, using the tolerance analysis capabilities in Inventor software to set the tolerance of the speed reducer gearbox. First, the dimensions of the conical rotor of the elevator gearbox were obtained by Geomagic reverse engineering software, and then the results were used in Inventor software to develop the gearbox model into a three-speed gearbox. Dimensional and geometric static tolerance analysis of this collection was done by using the worst-case, sum of square roots, process capability index and sigma methods. The results showed the worst-case method in tolerance analysis works more cautiously than other methods, as well as the residual sum of squares method, shows less laxity and interference than the worst-case method. Process index method, confirmed the assembly and in the sigma method, the sigma function considers the level of tolerance to be acceptable. Also, to ensure the correctness of the obtained tolerances, dynamic analysis has been done by using ADAMS software. The results showed that the set did not have any excessive slack or interference during movement.

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