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The Effect of Vibration against Geometrical Characteristics for Rotation Shaft System

K. Jafri, R. Ramli, A. H. Azman

Abstract*: *This paper presents several geometrical tolerance (GT) applications and vibration effects in rotational shaft. The impact of vibrations can damage critical components of machines such as bearings, gears and couplings and can be considered as benchmark for fundamental study to reduce the problem and improve the reliability of the components. Variations of GT in shaft models were applied to evaluate geometrical characteristics in translational and rotational parts featuring defects due to position and concentricity errors. The improvement of the shaft performance was conducted using finite element (FE) to establish minimum circumscribed, maximum inscribed and minimum zone. This approach is more accurate to the real model and assembly of mechanical system. The FE was compared with experimental results. Unconstrained vectors are used instead of the vibration frequency analysis to overcome the effects of the assumptions. Vibration frequencies were simulated by Finite Element Analysis of mechanical rotating shaft. It is found that concentricity characteristic has the highest magnitude compared to other characteristic. These effects should be taken into account in the design, installation and maintenance of rotating shafts. The impact and level of damage of the critical parts in the machine can be a benchmark for further studies for tolerance analysis and reliability.

Keywords* : *Geometrical Characteristic, Rotating Shafts, Finite Element Analysis (FEA), Shaft Misalignment, Rotational Speed..

I. INTRODUCTION

Computer-aided design (CAD) has been widely used by industries in designing new parts or products. Meanwhile, CAD based computer-aided tolerancing helps in designing the arts by analyzing geometrical deviations and behavior [1]. The standards of improving the Geometrical and Tolerance (GD&T) have been released by American Society of Mechanical Engineers (ASME) [2]. Generally, the geometrical deviation will cause variations of dimensions of parts due to its manufacturing imperfection. Hence, for a design engineer, it is important to take into consideration the tolerances effects in part designs. Designers must consider potential impacts to assess the integrity of a component [3]. The GD&T specifications includes tolerances of positions, dimensions and form [4]. A completely exact geometrical dimension in manufacturing parts is quite impossible and very expensive, hence variations are accepted [5]. Therefore, the usage of tolerance specifications indicates that variations of dimension, positioning and forms is still acceptable in manufacturing process.

Finite element methods (FEM) has been used in predicting geometrical values in non-linear variations by Coda [6]. The most essential factor in reducing variations in rotating machinery is rotary precision. The rotary precision which depends on many factors such as tolerance specifications, assembly and part deformation has a direct influence on the performance of the machine. Therefore, to improve the rotary precision performances, a tolerance analysis has a significant role in machine design process. One of the important factor in the machine design is the integration of bearings [7]. Tolerance analysis is performed with the purpose of error or defect such as mass imbalance and transitional alignment can be detected. Mazur et. al addressed the tolerance analysis problem in complex mechanical assemblies [8]. They found that there are still limitations of integrating tolerance analysis tools due to software capabilities.

Meanwhile, Guo et. al discussed a three dimensional tolerance analysis of displacements and deformations in rotating machineries such as bearings by using finite element analysis(FEA) [9]. Commonly, tolerance design software used now days are to ensure the accuracy in assembly process, shaft frequency simulation analysis, combination of simulation and tolerance analysis simulation imperatively. It is because, for the assembly tolerance simulation, preparation of tolerance analysis must be done in the previous simulation model. Most of the current assembly simulation software, during simulation verification, use ideal models with tolerances. Geometry information that will give impact to the shaft round will be obtained from the finite element and experimental results [10].

II. METHADOLOGY

A. Finite element analysis

In this paper, the approach is to analyze three geometrical tolerance characteristic which are straightness, parallelism, position and concentricity tolerances. A CAD model was proposed for designing a shaft component with geometrical tolerances using CATIA V5. The purpose of the analysis is to obtain a component with positional and form defects within the tolerance zone [11].

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***** Correspondence Author
K. Jafri*, PhD Student, Universiti Kebangsaan Malaysia. Email: P90553@siswa.ukm.edu.my
R. Ramli, PhD in Gifu University Japan. Email: rizauddin@eng.ukm.my
A. H. Azman, PhD from Univ. Grenoble Alpes, France Email: hadi.azman@ukm.edu.my

This paper covers the modal analysis of rotational shafts in which information is extracted from neutral CAD file format as STEP file and it integrated with CATIA V5 to CAE files. The STEP file format is suitable for this purpose since it is contained features, geometry and manufacturing information [12]. Figs. 1, 2 and 3 show the shaft design model for FEA analysis respectively. Fig. 4 shows a solid model of component arrangement for frequency analysis using ABACUS which is an FEA software.

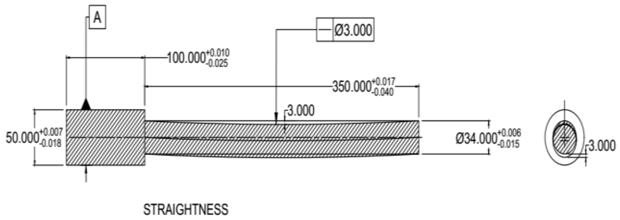

Fig. 1. Cross-section model for straightness characteristic

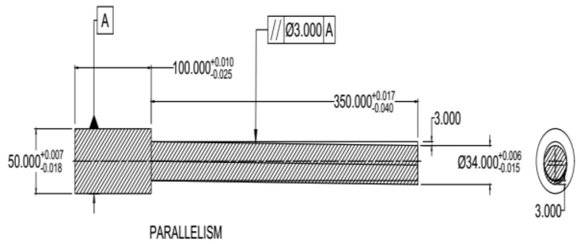

Fig. 2. Cross-section model for parallelism characteristic

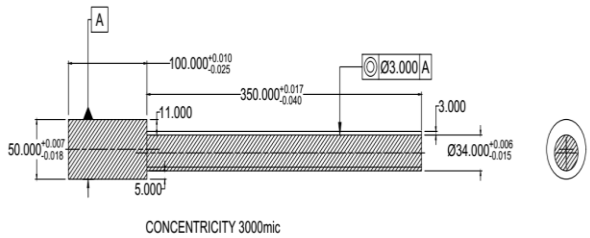

Fig. 3. Cross-section model for concentricity characteristic

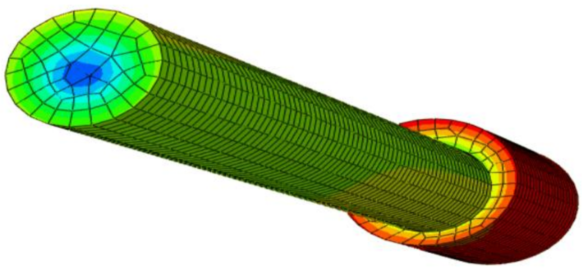

Fig. 4. Solid model component arrangement

B. Comparison with experimental result

In many geometrical tolerances (GT) applications, four main characteristics involved in shaft rotation, that is straightness, parallelism, concentricity and cylindricity. The shaft specimens are formed to its desired shape using a turning machine and also a press machine for bending the shaft to match the geometric characteristics of the shaft to be studied. The shaft specimens which are formed to different characteristics types were rotated in a turning machine and the spindle speeds are taken as parameter changes. Furthermore, we considered the shaft dimensions as unchanged parameters to obtain characteristics that cause the highest cause of vibration that affects the system. According to Louhichi et. al., for a rotating shaft, the centrifugal forces will directly influence its roundness depending on its rotating speed [13]. In this experiment, the shaft is rotated to measure the speed which is related to vibration energy and medium frequency range (10 Hz to 1 kHz). The detection of shaft misalignment and assessment of vibration severity by using ISO 10816 and JIS B 0906 as shown in Fig. 5. The procedure is repeated using another types of geometrical tolerance shaft.

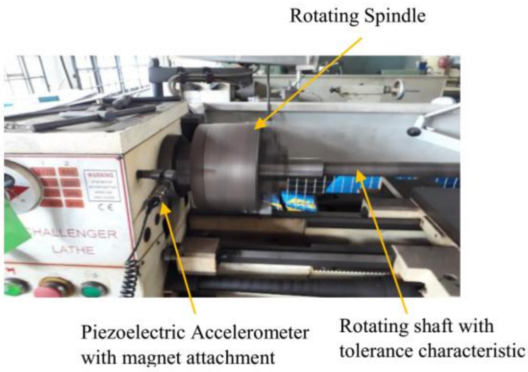

Fig. 5. Measurement of the vibration value

Table 1 and Fig. 6 shows that these characteristics will be varied with the response of a rotating system due to the unbalance excitation. Analyzes for experimental were performed on four types of characteristic namely cylindricity, straightness, parallelism and concentricity. From the results, it is found that concentricity characteristic provides a high amplitude value for all rpm, therefore it is concluded that the characteristic has a great impact on the shaft. This is due to imbalance force on the shaft effect of the characteristic. Measuring vibration using portable vibration analyzer VA-12 for equipment diagnosis and on site measurement with magnet piezoelectric accelerometer. All readings will be included in the data system and can be transferred to the user's computer.

Table-1: Data for geometrical characteristics and speed

GEOMETRICAL TOLERANCE (GT) CHARACTERISTICS	GT VALUE	UNIT	RPM 510	RPM770	RPM900
ZERO	0	mm/s	4.42E-01	3.65E-01	3.03E-01
CONCENTRICITY 1mm	1.313	mm/s	8.87E+00	2.70E+00	4.13E-01
CYLINDRICITY	2.201	mm/s	5.35E-01	5.35E-01	3.66E-01
PARALLELISM	2.372	mm/s	6.47E+00	6.50E-01	3.61E-01
STRAIGHTNESS	2.671	mm/s	4.87E+00	5.63E-01	4.45E-01
CONCENTRICITY 3mm	3.358	mm/s	1.29E+01	1.19E+01	7.69E-01
CONCENTRICITY 5mm	4.801	mm/s	1.40E+01	1.30E+01	9.51E-01

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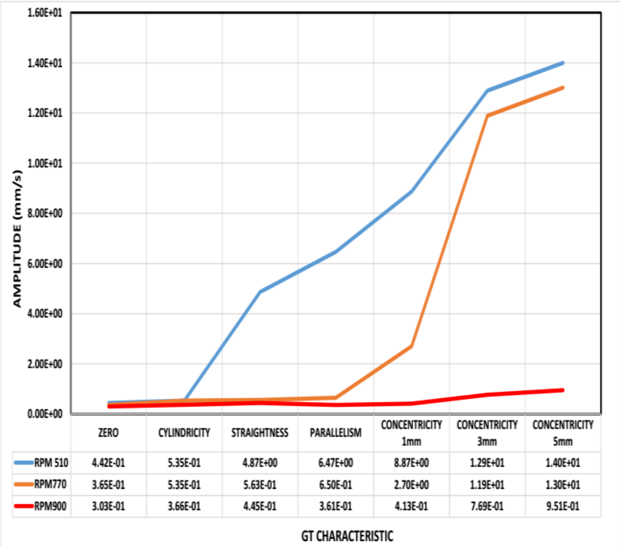

Fig. 6. Vibration amplitude for GC and RPM

III. RESULT AND DISCUSSION

A. Spatial displacement at nodes

Two methods for the geometrical tolerance analysis are applied in the study in by using Computer Aided Engineering (CAE) software. For nodal variables, except for axisymmetric elements, the data in the results are the output in the global directions. A quaternion representing the rotations of the global directions is extracted to the output. The CAE software transforms the nodal results to local directions and then stored in the global directions. Table 2 and Fig. 7 show the result of spatial displacement at nodes. The analysis is done for three characteristics namely parallelism, straightness and concentricity. It is found that concentricity characteristic produces a high magnitude which will give a great vibration effect to the shaft rotation and will affect the components involved.

Table-II: Result Spatial displacement at nodes

F, Frequency	U, Magnitude		
	Parellism	Straigness	Concentricity
1	1.89E-02	1.08E-02	1.23E-02
2	1.14E-01	1.09E-01	1.11E-01
3	2.08E-01	2.07E-01	2.10E-01
4	3.03E-01	3.05E-01	3.08E-01
5	3.98E-01	4.04E-01	4.07E-01
6	4.93E-01	5.02E-01	5.06E-01
7	5.87E-01	6.00E-01	6.04E-01
8	6.82E-01	6.98E-01	7.03E-01
9	7.77E-01	7.96E-01	8.01E-01
10	8.71E-01	8.94E-01	9.00E-01
11	9.66E-01	9.92E-01	9.99E-01
12	1.06E+00	1.09E+00	1.10E+00
13	1.16E+00	1.19E+00	1.20E+00

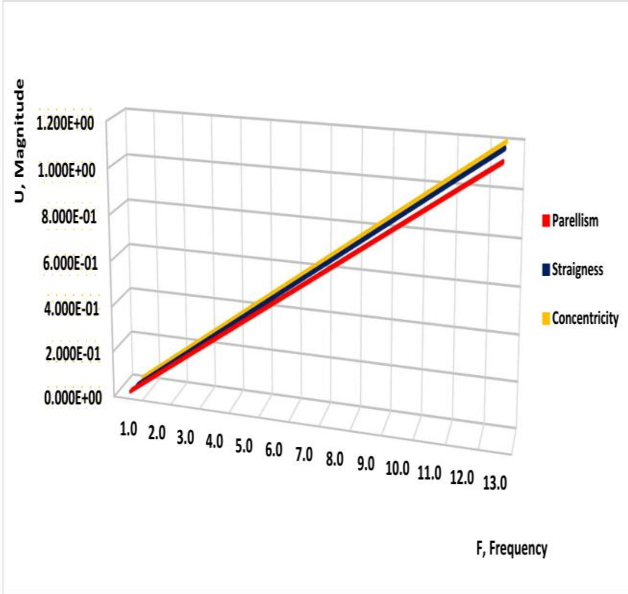

Fig. 7: Result Spatial displacement at nodes

B. Rotational displacement at nodes

The calculation of nonlinear dynamic analysis in FEA is based on time integration to obtain the transient dynamic or quasi-static deformation of a system. This can be applied to other applications such as numerical damping and tolerance analysis. Table 3 and Fig. 8 shows the result of the rotational displacements at nodes. For rotational displacement at nodes, it is also found that concentricity characteristic produces a high magnitude that will give a great vibration effect to the shaft rotation and will affect the components involved due to unbalance force for the shaft rotation.

Table- III: Rotational displacement at nodes

F, Frequency	U, Magnitude		
	Parellism	Straigness	Concentricity
1.0	0.000E+00	0.000E+00	0.000E+00
2.0	3.743E-03	3.269E-03	3.811E-03
3.0	7.486E-03	6.539E-03	7.621E-03
4.0	1.123E-02	9.808E-03	1.143E-02
5.0	1.479E-02	1.308E-02	1.524E-02
6.0	1.872E-02	1.635E-02	1.905E-02
7.0	2.246E-02	1.962E-02	2.286E-02
8.0	2.620E-02	2.289E-02	2.667E-02
9.0	2.994E-02	2.615E-02	3.049E-02
10.0	3.369E-02	2.942E-02	3.430E-02
11.0	3.743E-02	3.269E-02	3.811E-02
12.0	4.117E-02	3.596E-02	4.192E-02
13.0	4.492E-02	3.923E-02	4.573E-02

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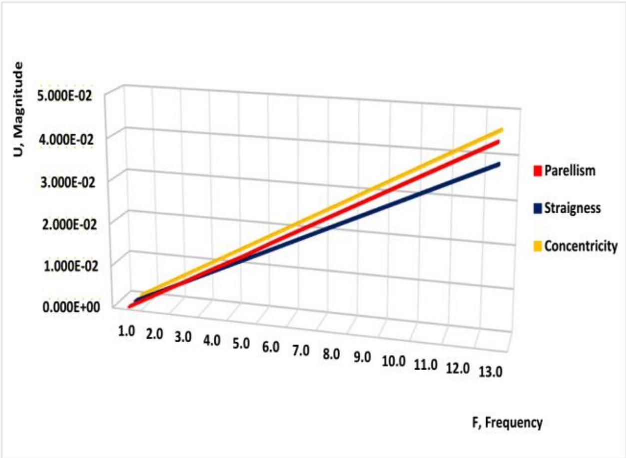
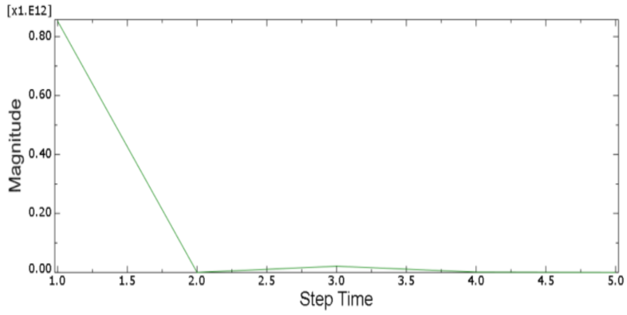


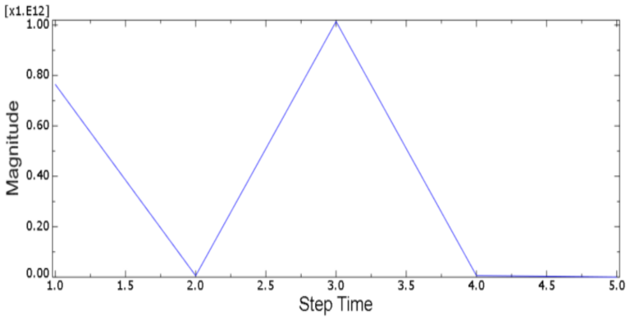
Fig. 8. Rotational displacement at nodes

C. Effective Mass, Y- rotation for whole model

The sum of effective masses of all modes are added in all directions. Therefore, if the effective masses of the modes are lower that the total mass, this shows that the modes have significant excitation in the direction. Fig. 9 shows the effective mass, rotated along the Y-axis, the (a) concentricity, (b) straightness and(c) parallelism.



(a)



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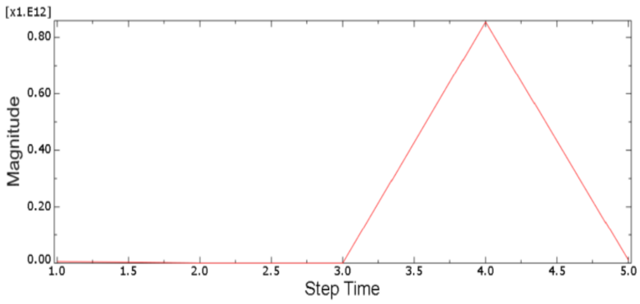
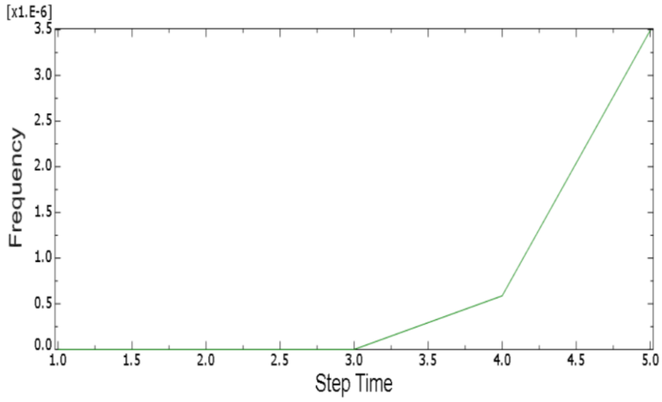


(c)

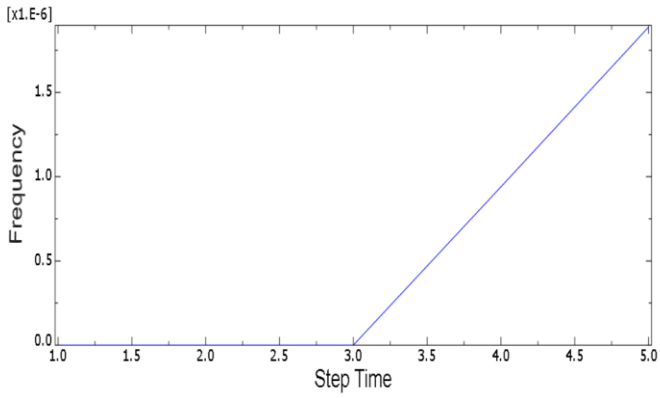
Fig. 9. Effective Mass, Y- rotation for whole Model a) Concentricity b) Straightness c) Parallelism

D. Frequency for whole model

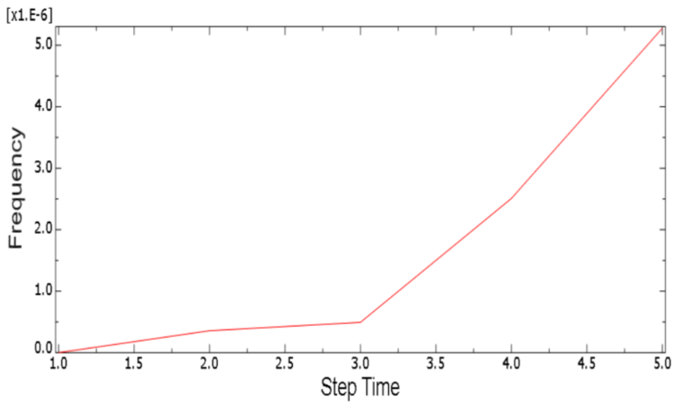
The frequency of the model is calculated. The factors taken into account are the initial stress, load, stiffness effects. Small vibrations can be modelled in the FEA software and compute residual modes. Fig. 10 shown Frequency for whole model a) Concentricity, b) Straightness and c) Parallelism.



(a)



(b)



(c)

Fig. 10. Frequency for whole model a) Concentricity, b) Straightness and c) Parallelism

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IV. CONCLUSION

This paper analyses the effects of geometrical characteristics using FEA for a rotational shafts. Concentricity was found to have a significant impact on the shaft rotation, for example concentricity 3358 micron for the rpm 510 vibration value is 1.29E + 01 mm/s, rpm 770 vibration value is 1.19E+01 mm/s, rpm 900 vibration value is 7.69E-01 mm/s. Tolerance is an acceptable range of the deviation from a given dimensions. This papers found that the range of value in the results of the experiment is greater than the finite element analysis which has a small range of value. It is found that concentricity characteristic has the highest magnitude compared to other characteristic. It is found that experimental and finite element results are parallel where both the results state that concentricity characteristic has a high magnitude value. Therefore, the concentricity characteristic will have a great impact on the vibration system if the geometrical tolerance is not taken into account properly.

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AUTHORS PROFILE

Jafri, K, PhD student in geometrical Tolerance at the Centre for Materials Engineering and Smart Manufacturing (MERCU), Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia. Currently he is working as Vocational Training Officer in the Department of Plant Maintenance, Mara Higher Skill College, Lenggong, Perak, Malaysia. His research interests are mechanical design.

Rizauddin, R, completed his PhD in Gifu University Japan. Currently he is working as Associate Professor in the Centre for Materials Engineering and Smart Manufacturing (MERCU), Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia. Her research interest Robotics & Intelligent Manufacturing Systems.

Azman, A. H, completed his PhD from Univ. Grenoble Alpes, France. Currently he is working as Senior Lecturer in the Centre for Integrated Design of Advanced Mechanical System (PRISMA), Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia. His research interest Mechanical Engineering Design