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ANALYSIS OF THE INFLUENCE OF FILLET GEOMETRY ON STRESS CONCENTRATION IN KEYWAY BY THE FINITE ELEMENT METHOD

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ABSTRACT

Machines are of great importance in the modern world, as activities are facilitated due to their energy conversion capacity, being able to transform electrical energy into mechanical energy, for example. In this sense, the mechanical axis is of great importance because, through it, it is possible to transmit power for the most varied types of activities. As a solid body, this component is subject to mechanical stress and the keyway, present in the shaft, increases the stresses in the geometry, which is undesirable as it facilitates its rupture, thus, the study of alternatives for reducing the stress concentrator appear as an interesting path. This work proposed to investigate the influence of fillet geometry on stress concentration in parallel keyways under bending efforts, using simulations using the finite element method. The study compares elliptical fillets with circular fillets and evaluates how the variation of parameters impacts the stress concentration, where the tool used to carry out the analysis of the present work was Ansys. The results indicate that small changes in the fillet geometry can reduce the stress concentration. This study contributes to the optimized design of mechanical components and offers insights for engineers working in the field.

Keywords: *Elliptical Fillet, Stress Amplification, Numerical Simulation, Mechanical Design.*

INTRODUCTION

In the modern world, machines have been gaining more and more space in everyday activities, where in the mechanical industrial sector, for example, machines tend to operate by being driven by electric motors [1]. The shaft power, developed when driving the motor, needs to be transmitted to the other rotating components of the system, for this purpose, certain parts are used that are intended to transmit torque and rotation.

The key is an example of a part that is usually used to transmit torque and rotation between components, it is coupled to the shaft and the other element to prevent relative rotation and has standardization of design, with the parallel key being the most common variation [2].

For the coupling, it is necessary that both elements, the shaft and the other rotating component, are machined, thus implying tension amplification in the notch created.

Axles are mechanical elements with the purpose of transmitting torque to other coupled equipment, and may be subjected to axial, torsional and bending stresses. Keyways are stress concentrators on shafts and high mechanical stresses are undesirable as they affect the performance expected in the project, and can therefore greatly increase the safety factor in static and dynamic loads [3]. Pedersen [4] investigated the reduction of stress concentration in parallel keyways subjected to torsional stress by modifying the fillet geometry and found that the fillet geometry that minimizes the stress concentration by about 50% can be modeled by an ellipse.

The present work aims to investigate the influence of the elliptical fillet on the stress concentration in parallel keyways subjected to bending efforts, through numerical simulation, seeking optimized patterns that reduce stress gradients. To this end, the present study is arranged in 5 topics, where Topic 1 brought a brief introduction to the work, Topic 2 will show the methodology approached for carrying out of the study, Topic 3 will show the results obtained and Topic 4 will show the conclusion.

MATERIALS AND METHODS

Shaft and keyway

To create the geometry to be analyzed, the SolidEdge software was used, which is freely available for academic use, where in the axis to be analyzed the diameter was arbitrated as 28 mm and, according to DIN 6885-1 [2], the geometry of the keyway was defined with W = 8 mm and H = 7 mm, depending on the diameter, and it was decided that the length of the key would be equal to the width, so W = L = 8 mm.

To define the length of the axis, the Saint-Venant principle was used, which states that loads applied to a body cause purely local effects, thus, the tension tends to fall quickly as the distance increases [5]. Based on this principle, the tension is redistributed after a discontinuity, where this distribution will tend to an average tension, with this depending on the distance to the discontinuity, therefore, some simulations were carried out with the variation of the axis length so that the tension of flexion generated on the right face was equal to that on the left face, thus being equal to the nominal flexural stress, that is, without the effect of the stress concentration of the keyway. That being said, the geometry of the keyway in the shaft is shown in Fig. 1.

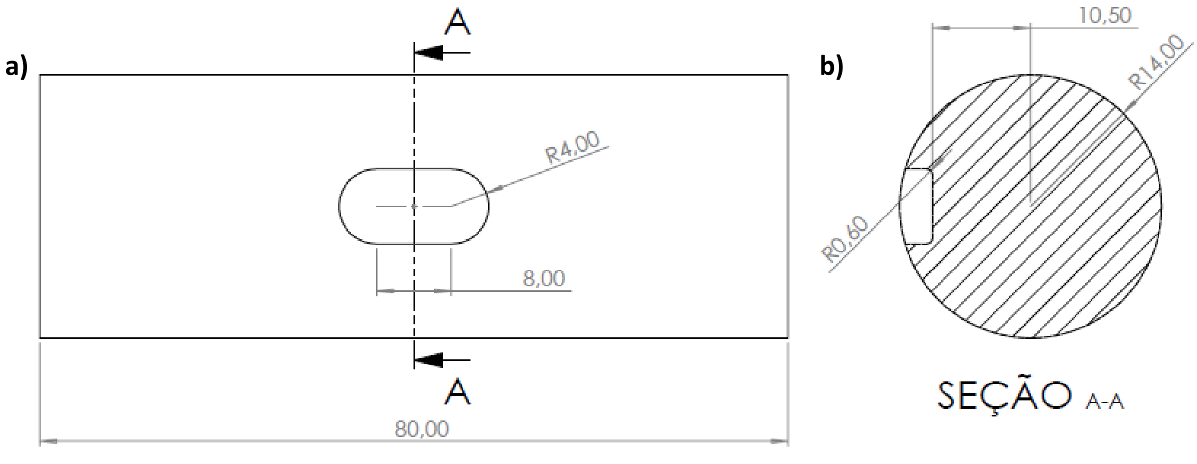

Fig. 1. Shaft geometry for simulation a) full view, b) section A-A (Author, 2023)

Elliptical and circular fillets

In the case of a circular fillet, the stress concentrator for the fillet will first be calculated numerically. In this way, it will be possible to compare such results with results present in the literature and select boundary conditions and mesh parameters in order to obtain accurate results. Regarding the elliptical fillet, its geometry parameters are defined based on the circular fillet, where a circular fillet with r = 0.4 mm was selected as a comparison parameter for the elliptical fillets. The Fig. 2 shows the details of both fillets.

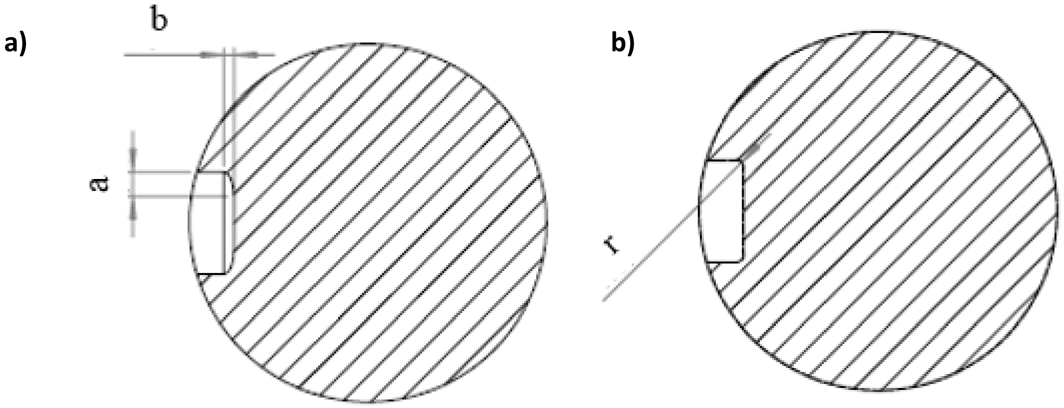

Fig. 2. Geometrical parameter of the fillets a) elliptical, b) circular (Author, 2023)

In the analysis of the elliptical fillet, parameter b will have its value fixed at 0.4 mm, while the parameter a will be changed in order to obtain different a / b ratios within the range of 0.5 to 2. It is important to highlight that a ratio a / b equal to 1 result in a circular fillet with r = 0.4 mm, thus allowing a comparison between numerical values and literature data.

Numerical simulation

For the numerical simulation, the Ansys Software was used, which has a student version available free of charge, and through it the mesh was generated and the boundary conditions of the problem were informed. The Fig. 3 shows the geometry and boundary conditions imposed on the problem.

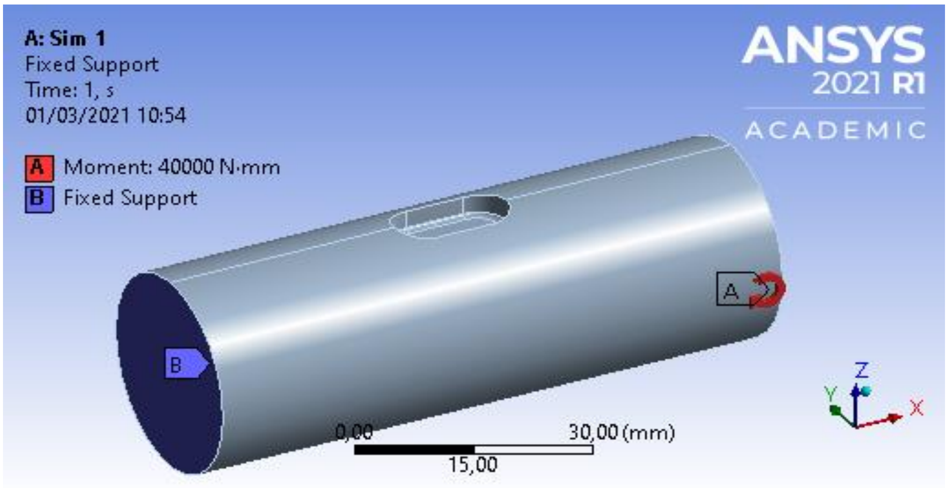

Fig. 3. Boundary conditions (Author, 2023)

In this image it is possible to observe the boundary conditions placed in the geometry, where the left face in blue is fixed and a bending moment of 4000 N.mm is applied to the opposite face. Regarding the structure of the mesh, it will be composed of tetrahedral elements and the curvature method will be used in order to achieve adequate refinement in the fillet region. Furthermore, the size of the element on the fillet face will be limited to r/2 in the case of a circular fillet and to a/2 in the case of an elliptical fillet.

RESULTS AND DISCUSSION

<u>Model validation</u>

With the aim of validating the numerical model, a mesh convergence study was carried out and compared with experimental data present in the literature. The Fig. 4 shows the stress concentration values obtained numerically in comparison with the values obtained by Fessler et al. [6].

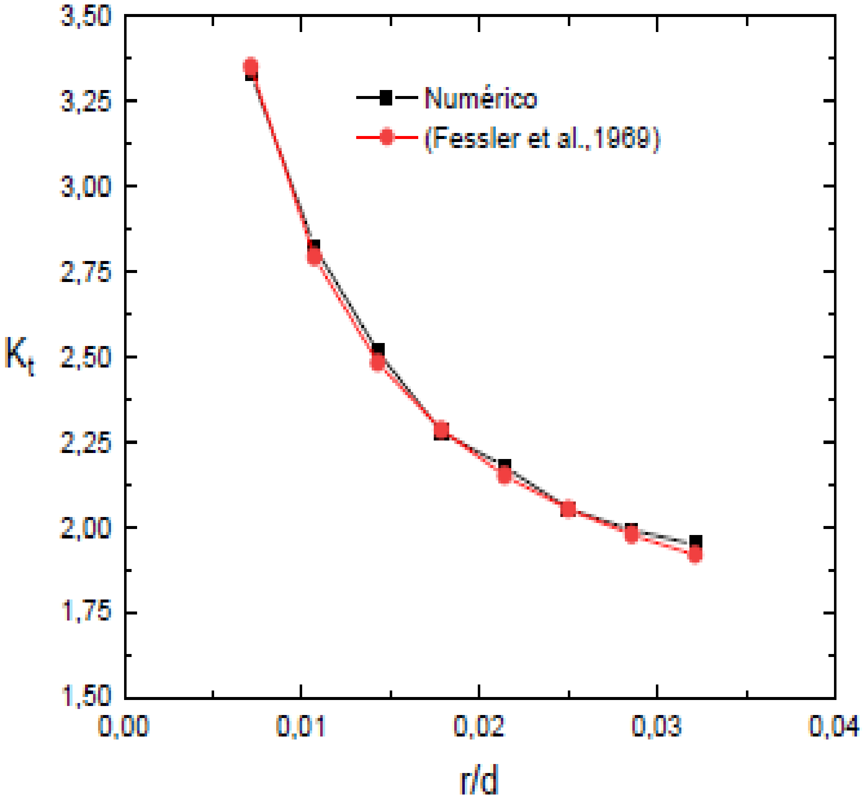

Fig. 4. Stress concentration factor for the circular fillet (Author, 2023).

The average relative error of the numerical factor obtained in relation to those obtained in the literature was 1.52%, thus indicating that the modeling and mesh parameters are satisfactory for describing the physical problem. The Equation (1) shows the equation adjusted to the values obtained by Fessler et al. [6], where r/d belongs to the range 0.005 – 0.040.

$$K_t = 1{,}4260 + 0{,}1643 \, . \left(\frac{0{,}1000}{r/d}\right) - 0{,}0019 \, . \left(\frac{0{,}1000}{r/d}\right)^2 \qquad (1)$$

Analysis of fillets and stress concentration

The Fig. 5 shows the results obtained for the elliptical fillet using the circular fillet, with r = 0.4 mm, of the already validated model as a basis for comparison. For the purposes of validating the elliptical fillet model, it is possible to observe at the point where a = b = r = 0.4 mm there is a relative error of 4.62% between the results obtained for the elliptical fillet and the circular fillet, indicated by the blue arrow. In numerical simulation, considering computational restrictions, this dispersion of values is acceptable

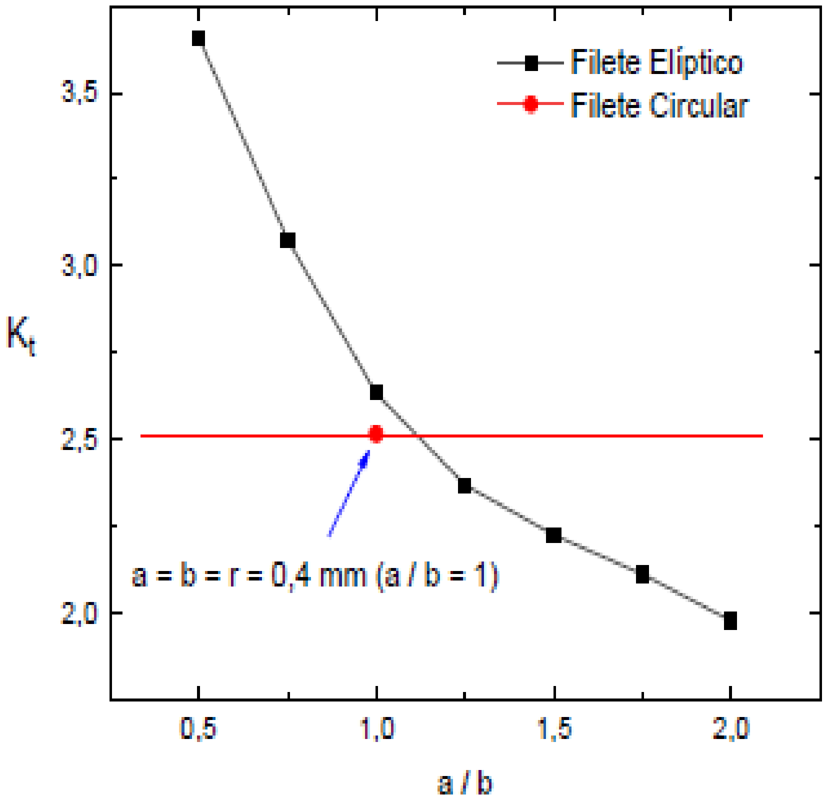

Fig. 5. Circular fillet and elliptical fillet stress concentration factor (Author, 2023)

The results show that, for a/b ratios greater than 1, the stress concentration decreases. In view of this, Perdersen [4] described the same behavior for the stress concentration under torsional efforts, showing the importance that this type of geometry can have with respect to static load applications. However, when decreasing the ratio, it was observed that the stress concentration increases abruptly. This behavior suggests that this geometry borders on discontinuity and, therefore, this phenomenon was already expected.

The maximum stress occurs on the elliptical fillet of the geometry in almost all cases, except only for the ratio a / b =2. In cases where the maximum tension occurs in the fillet, it is possible to say that the use of this structure replaces the traditional circular thread, where with the correct parameters it can greatly reduce the maximum tension obtained in the shaft. Next, the Fig. 6 shows the equivalent stress distribution in the geometry with a ratio equal to 2 in the fillet.

It is possible to observe that the maximum stresses are concentrated on the walls of the notch, reaching values just above 35 MPa, however, even with the difference in the region where the maximum stress occurs when compared to the others, it is important to highlight that the elliptical fillet reduces discontinuities and consequently tensions.

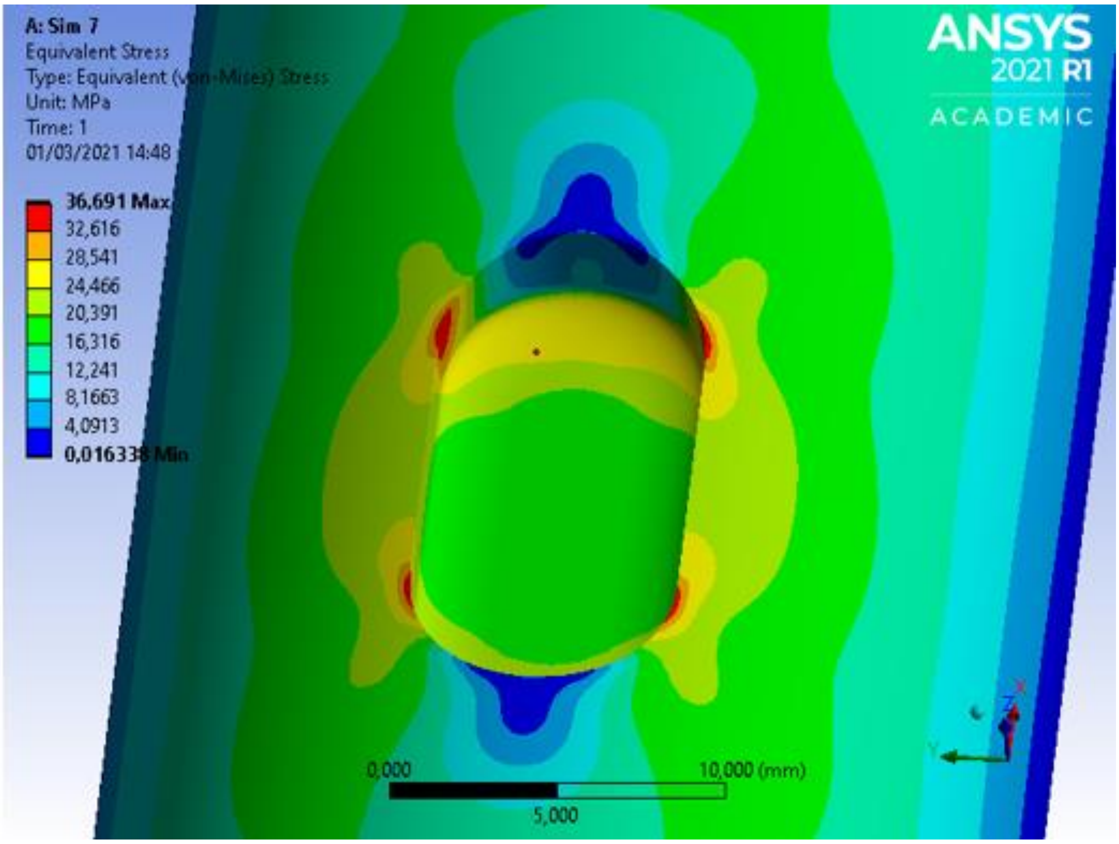

Fig. 6. Stress distribution in the keyway with elliptical fillet and a/b=2 (Author, 2023)

CONCLUSIONS

This study denotes the power of the numerical tool in modeling the stress concentration factors in a keyway under flexion. In other words, it is possible to obtain, for the circular fillet, values very close to those of other studies with a reduced cost/accuracy ratio, validating the simulation carried out. Furthermore, it can be concluded that:

- The numerical model achieved the work proposal well;
- Small changes in the fillet geometry can reduce stress concentration, as the elliptical fillet with a ratio a / b = 1.25 achieved a reduction of 9.98% in the stress concentration factor in relation to the circular fillet, resulting in a considerable reduction;
- As the a / b ratio increases, the reduction in concentration follows the same trend, with the maximum reduction being 24.90%;
- The model with elliptical fillet, in all cases, manages to reduce the maximum stresses on the shaft, however, it is necessary to carry out a new study with dynamic loads to obtain more relevant results for the application of shafts.

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