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Analysis and Validation of Kennedy Key

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***Abstract-* This paper entails the design of Kennedy Key complying with the theory of machine design which is validated by Finite Element Analysis to provide a realistic solution to overcome the assumptions in the numerical solution. A comparative study is also conducted to observe the equivalent stress distribution, total deformation, shear stress, normal stress and factor of safety (fs) of the key based on variations in length and cross sectional area under same loading and constrain conditions. The study is done to analyse the key in dynamic conditions so as to ensure the key is designed to sustain the loads and avoid failure.**

Keywords- FEA, fs, stress, Kennedy Key, Ansys

I. INTRODUCTION

A key is a machine element which is used to connect the transmission shaft to rotating machine elements like pulleys, gears, sprockets or flywheels. The primary function of the key is to transmit the torque from the shaft to the hub of the mating element and vice versa. The secondary function of the key is to prevent relative rotational motion between the shaft and the joined machine element. A recess or slot is machined either on the shaft or in the hub to accommodate the key is called keyway. The main drawback of a keyed joint is that the keyway results in stress concentration in the shaft and the part becomes weak. Keys are made of plain carbon steels in order to withstand the shear and compressive stresses resulting from transmission of torque. Many types of keys are available and there are a number of standards which specify the dimensions of the key. The selection of the type of key for a given application depends on factors like power to be transmitted, tightness of fit, stability of connection and cost [1].

In this paper Kennedy Key is discussed and analysed in detail. The Kennedy key consists of two square keys. The hub is bored off the centre and the two keys force the hub and the shaft to a concentric position. Kennedy key is used for heavy duty applications. The analysis of the Kennedy key is based on two criteria which are failure due to shear stress and failure due to compressive stress.

Since there are two keys, the torque transmitted by each key is one half of the total torque. The two equal and opposite forces are due to the transmitted torque. The forces are assumed to act tangential to the shaft diameter.

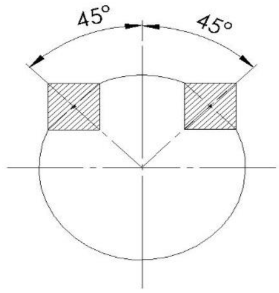

Fig. 1. Cross-Section of Kennedy Key

II. OBJECTIVE

The study is conducted with the following objectives:

- To validate numerical solutions through the well-developed finite element analysis solvers.
- To study comparatively the effect of variations in length and cross sectional area of key on stress, factor of safety and deformation.

III. CASE SPECIFICATIONS

Simulation of key requires the designing of a key. The foundation of designing a key lay in its application. Hence, a general application has been considered for designing the required key [1].

The data considered is shown in Table-1.

TABLE 1. CASE SPECIFICATIONS

Shaft Diameter	40 mm
Power	35 kW
RPM	300
Material	Steel 45C8
Cross-section of Key	10 x 10 mm
Factor of Safety	3

IV. MATERIAL PROPERTIES

The material selected for the Kennedy key is Steel 45C8. The mechanical properties and chemical composition of the material are given in Table-2 and Table-3 [2].

TABLE 2. MECHANICAL PROPERTIES

PROPERTY	VALUE
Density	7.85 g/cm^3
Elastic Modulus	210 GPa
Poisons Ratio	0.3
Yield Strength	380 MPa
Ultimate Tensile Strength	630 MPa

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TABLE 3. CHEMICAL COMPOSITION

ELEMENT	CONTENT
Carbon	0.4%
Manganese	0.6%
Silicon	0.15%
Aluminium	0.02%

V. ANALYTICAL SOLUTION

The key is designed by solving the considered application analytically complying with the theory of machine design. The key is analysed by its free body diagram. The forces acting on the Kennedy key are shown in Fig. 2. The shear stress and the compressive stress are given by $\tau = \frac{M_t}{\sqrt{2}dbl}$ and $\sigma_c = \frac{\sqrt{2}M_t}{dbl}$ respectively [1].

A. Permissible compressive and shear stresses

$$\sigma_c = \frac{S_{yc}}{fs} = \frac{380}{3} = 126.67\ N/mm^2$$

According to distortion energy theory of failure,

$$S_{sy} = 0.577 S_{yt} = 0.577(380) = 219.26\ N/mm^2$$

$$\tau = \frac{S_{sy}}{fs} = \frac{219.26}{3} = 73.09\ N/mm^2$$

B. Torque transmitted by shaft

$$M_t = \frac{[60 \times 10^6 \times (kW)]}{2\pi n} = \frac{[60 \times 10^6 \times 35]}{2\pi(300)}$$
$$= 1114084.6\ N - mm$$

C. Key length

Using the formula of shear stress on the key, we get

$$l = \frac{M_t}{\sqrt{2}db\tau} = \frac{1114084.6}{\sqrt{2}(40)(10)(73.09)} = 26.95\ mm$$

And using the formula of compressive stress, we get

$$l = \frac{\sqrt{2}M_t}{db\sigma_c} = \frac{\sqrt{2}(1114084.6)}{(40)(10)(126.67)} = 31.10\ mm$$

Thus, from the analytical solution obtained above we can estimate the length of the key to be approximately 30mm to get a factor of safety of 3.

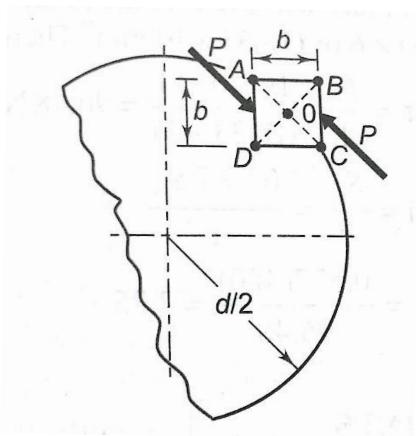

Fig. 2. Forces acting on Kennedy Key

VI. NUMERICAL SOLUTION

The key is initially designed according to the specifications of application considered and using the analytical solution as well. The designing is done in SolidWorks which is a 3D CAD design software developed and marketed by Dassault Systèmes while the analysis is carried out in Ansys which is an engineering simulation software developed and marketed by Ansys, Inc. to obtain a numerical solution.

Fig. 3. Kennedy Key fitted in keyway in a shaft

A. Finite Element Analysis

FEA is a method in which the model is discretized into small elements, properties of which are then evaluated using general equations of motion and boundary conditions specified during a test. This involves solution of the equation:

$$[\text{Reaction}] = [\text{Stiffness}] * [\text{Displacement}] + [\text{Load}]$$

B. Boundary Conditions

The boundary conditions in finite element analysis comprises of the loads and constraints applied over a region or part in which a set of differential equations needs to be solved.

In the case of Kennedy key in application, shear and compressive loads are being applied while the movement of the key is constrained in particular directions due to the shaft and hub between which it is fitted. The loading diagram of the key is shown in Fig. 4.

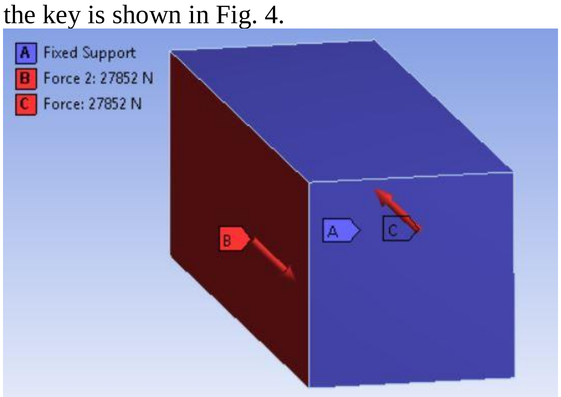

Fig. 4. Boundary Conditions applied on Key

C. Mesh Generation

This process involves the solid model of key being discretized into small elements and thus equations are solved on nodes resulting from meshing of elements. To obtain a more accurate solution, a fine mesh is generated in Ansys Mechanical which consists of elements of very small size as shown in Fig. 5. The mesh statistics are given in Table-4.

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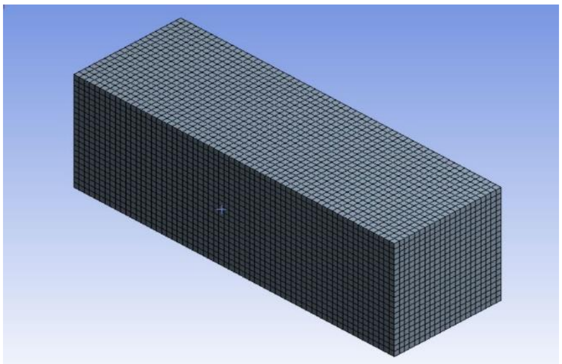

Fig. 5. Mesh

TABLE 4. MESH STATISTICS

Nodes	118712
Elements	27342
Size Function	Proximity and Curvature
Relevance Center	Fine
Span Angle Center	Fine
Minimum Edge Length	1.e-002 m

D. Solution

The mesh obtained is solved for the applied boundary conditions using finite element solvers to obtain an accurate solution in terms of equivalent stress, normal and shear stress and the factor of safety. The results are displayed below.

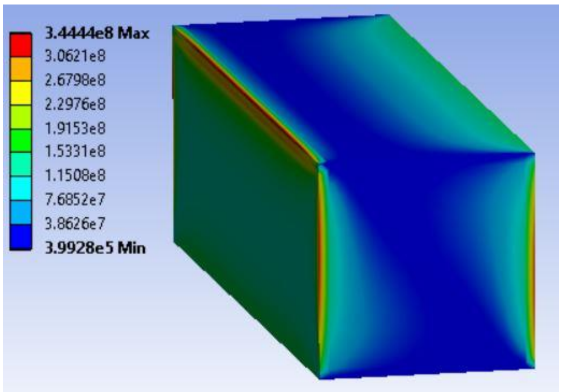

Fig. 6. Equivalent Stress

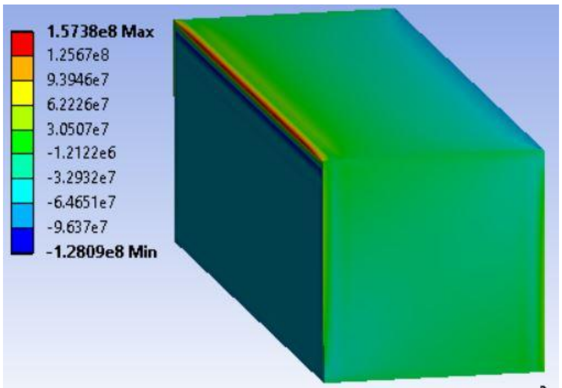

Fig. 7. Normal Stress

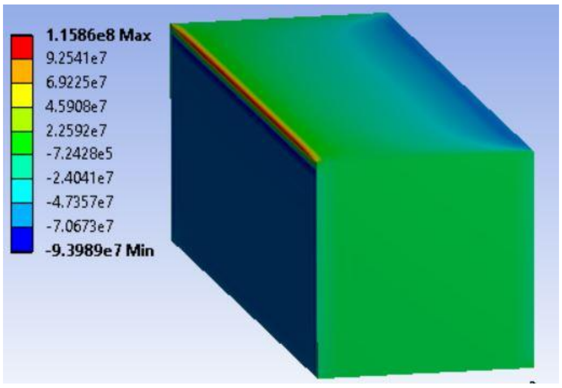

Fig. 8. Shear Stress

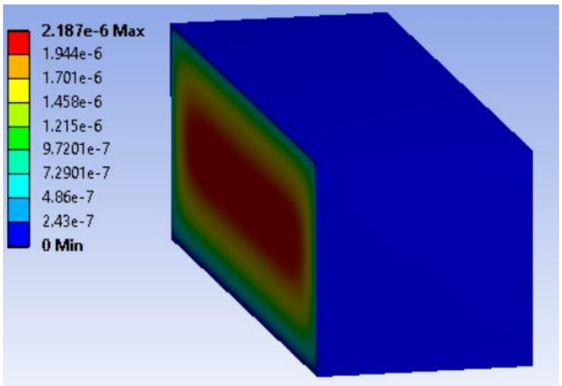

Fig. 9. Total Deformation

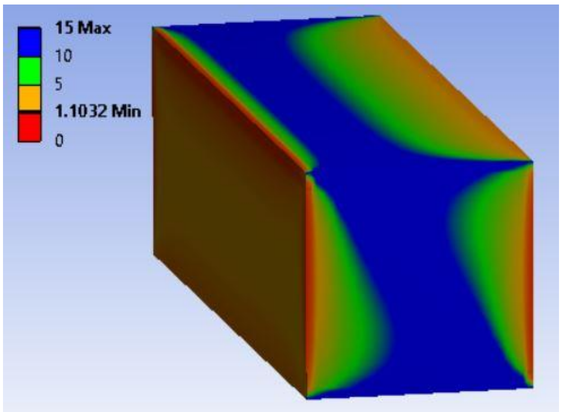

Fig. 10. Factor of Safety

VII. EFFECT OF VARIATIONS IN LENGTH AND CROSS-SECTION

To develop a better understanding of stress distribution, stress concentration and the resulting factor of safety, a comparative study is conducted by varying the length and cross section of the Kennedy Key and subsequently plotting graphs of equivalent stress, normal and shear stress, factor of safety versus the varying length and cross-section as shown in Fig. 11 and Fig. 12. Conclusions are based upon the interpretation of these graphs. Thus, from these graphs optimum length and cross-section of the Kennedy Key can be determined for a specific application for complying with the recommended minimum value of factor of safety to be kept while designing the key according to industrial standards.

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Fig. 11. Variations in stress with length for different cross-sections

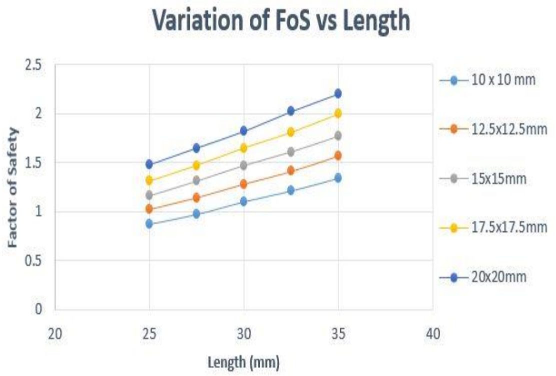

Fig. 12. Variations in factor of safety with length for different cross-sections

VIII. CONCLUSIONS

The Kennedy Key is designed based upon the analytical calculations and then analysed through the finite element analysis in Ansys Workbench with relevant boundary conditions. The numerical and analytical solutions differ by a considerable amount for the compressive stress, shear stress as well as the factor of safety. An increase in the magnitude of normal and shear stresses from the analytical results in an increase in equivalent stress and eventually a reduction in factor of safety from a value of 3 as per the key is designed to a value of 1.1 which is obtained through the FEA solution. This is due to the fact that in analytical solution the part is assumed to have uniform factor of safety throughout the body but it varies throughout the regions of part due to varying geometrical sizes and thickness. The region having lowest factor of safety is most likely to fail or fatigue during the part lifetime. Hence, the key should be designed such that the factor of safety in no region falls below 1.5 which is taken as reference to industrial standards. Hence, for the particular application considered, the dimensions of the Kennedy Key has to be changed to increase the minimum factor of safety from 1.1 to 1.5. This iterative process can be assisted by the comparative study in which variations in equivalent stress and factor of safety with length have been plotted on the graph for different cross-section areas. The graphs can be interpreted to select the optimum dimensions of cross-section and length of the Kennedy Key for obtaining required magnitudes of factor of safety required for the specific application.

IX. REFERENCES

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