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Modelling And Analysis Of An Electric Motor Shaft Varying It's Length

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***Abstract:** Electric motors are well known as 'Basic Prime movers' for Engineering Applications. Stresses in rotor shafts are complex, normally involving combinations of bending, torsion, and shear. Some stresses alternate or reverse in direction with each shaft revolution; others may be cyclically varying. The interest is to study the stress in the rotor shaft in electric motor. In this study a validation of design carried out with FEA solution is done. Modelling of the revised shaft is done by considering all boundary conditions and extreme load conditions. The analysis is done considering various types of loading conditions. Stresses, deflections and safety factors of the shafts are checked by commercial finite element analysis software (ANSYS 14.1). The obtained values from static analysis of both standard shaft design and revised shaft design is compared.*

***Keywords:** Shaft, Stress, FEA, Modelling, Ansys, Load.*

I. INTRODUCTION

A shaft is a rotating machine element, usually circular in cross section, which is used to transmit power from one part to another or from a machine which produces power to a machine which absorbs power. Shaft is common component used in variety of applications across industries. This is typical shaft used in motor which carries rotary components. The motor rotor shaft is designed on the basis of static and dynamic loadings. The design is validated analytically for static case and pattern is observed. Stresses, deflections and safety factors of the shafts are checked by commercial finite element analysis software (ANSYS). Stresses in rotor shafts are complex, normally involving combinations of bending, torsion, and shear. Some stresses alternate or reverse in direction with each shaft revolution; others may be cyclically varying.

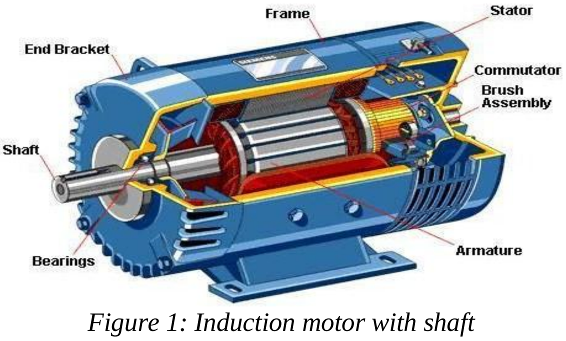

Figure 1: Induction motor with shaft

The stator, shown in Fig. 1, is the outer stationary part of the motor. It consists of outer cylindrical frame, the magnetic path and a set of insulated electrical windings. Rotor is the rotating part of the motor. It is placed inside the stator bore and rotates coaxially with the stator.

II. FAULTS: CAUSES AND EFFECTS

Induction motors are rugged, low cost, low maintenance, reasonably small sized and operating with an easily available power supply. They are reliable in operations but are subject to different types of undesirable faults. From the study of construction and operation of an induction motor, it reveals that the most vulnerable parts for fault in the induction motor are bearing, stator winding, rotor bar, and shaft. Faults in induction motors can be categorized as Electrical-related faults, Mechanical-related faults and Environmental-related faults. Motor shaft i.e. rotor and its faults fall under Mechanical-related faults. The squirrel cage of an induction motor consists of rotor bars and end rings. If one or more of the bars is partially cracked or completely broken, then the motor is said to have broken bar fault. If the rotor is not centrally aligned or its axis of rotation is not the same as the geometrical axis of the stator, then the air gap will not be identical and the situation is referred as air-gap eccentricity. In fact, air-gap eccentricity is common to rotor fault in an induction motor. Air-gap eccentricity may occur due to any of the rotor faults like rotor mass unbalance fault, bowed rotor fault, etc.

III. FACTORS TO BE CONSIDERED WHILE DESIGNING THE SHAFT

- ✓ Determine External Loads.
- ✓ Identify Critical Shaft Sections.
- ✓ Determine deflection and critical speed
- ✓ Determine Stresses.
- ✓ Choose Material & Material Properties.
- ✓ Determine Safety Factors.

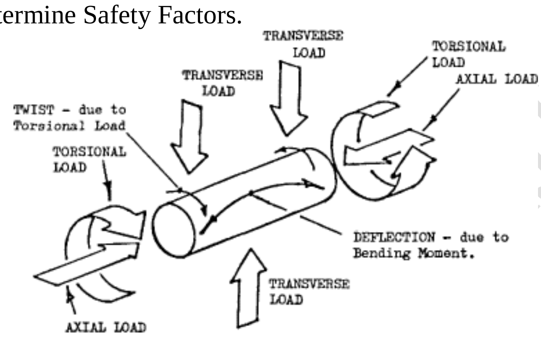

Figure 2: Loads applied to shaft during power transmission

Actual loads must be determined with reference to the functional requirements of the system. Figure 2 shows typical loads applied to a shaft during power transmission and the resultant deflections. Loads include torsional loads, transverse loads, axial loads, twist and deflection'

Critical sections are sections likely to be subjected to high stresses. Locate critical sections by inspection, with reference to the applied loads. Critical sections are usually associated with changes of shaft section or points of load application. Deflection of shaft directly influences the critical speed. Critical speed is a speed at which the shaft will be under resonance. Critical speed is determined by the formula,

$N_c = \frac{1}{2}\pi \sqrt{(g/\partial)}$

Stresses are induced in the shaft, due to rotor load, torque from stator, radial load & torque at shaft extension. Based on these factors the minimum diameter of the shaft shall be calculated.

Material choice is constrained by many considerations involving performance, manufacturing and commercial factors. In practice, the apparently wide choice is limited (for shafts) to only a few. The factor of safety reflects the designer's confidence in the data used and the consequences of failure.

IV. MODELLING OF SHAFT

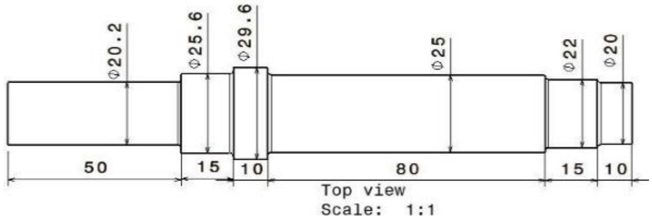

Figure 3: Dimensions of regular shaft

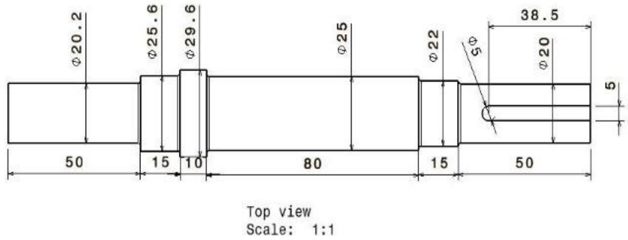

Figure 4: Dimension of extended shaft

3D modeling or CAD (Computer Aided Design) allows engineers and designers to build realistic computer models of parts and assemblies. Modeling is the computer modeling of 3D solid objects. The objective of Solid Modeling is to ensure that every surface is geometrically correct. computer-aided design and drafting (CADD), is technology for design and technical documentation, which replaces manual drafting with an automated process.

CATIA software is a multi-platform software suite for computer-aided design (CAD).

Drawing of regular shaft and extended shaft with proper dimensions is done after which modelling of the shaft is done using catia. Taking stress concentration into account the sharp edges are given a filled of 1mm.

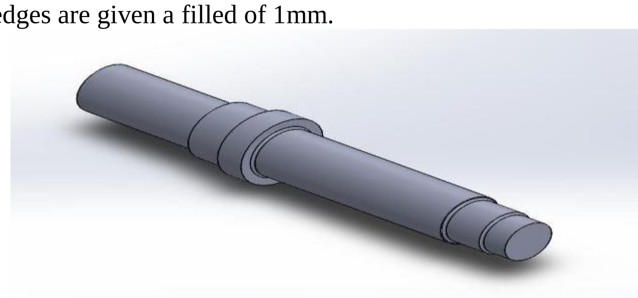

Figure 5: CATIA model of shaft

V. MESHING OF SHAFT

It is a process of sub dividing the model in to finite elements which helps in analyzing the individual, which gives the final summation value. Meshing is a discrete representation of the geometry that is involved in the problem. Essentially, it partitions space into elements (or cells or zones) over which the equations can be approximated. Zone boundaries can be free to create computationally best shaped zones, or they can be fixed to represent internal or external boundaries within a model.

Mesh is done with following statistics, 314366 elements

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and 449023 nodes for normal shaft and 59820 elements and 103963 nodes for extended shaft. More the number of elements higher the accurate value. Finer the size of mesh increases the accuracy of the result. This process is done using the analysis tool – Ansys workbench. Quadrilateral type of Elements are used for meshing.

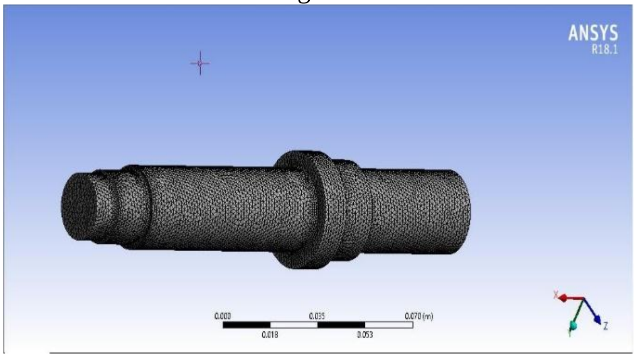

Figure 6: Finite element model of regular shaft

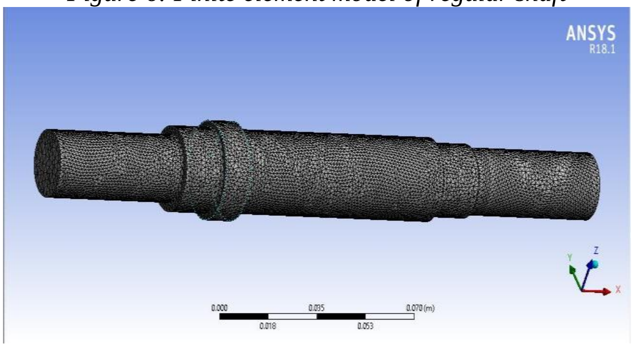

Figure 7: Finite element model of extended shaft

VI. APPLING LOAD AND BOUNDARY CONDITIONS

A. LOAD ON FLANGE

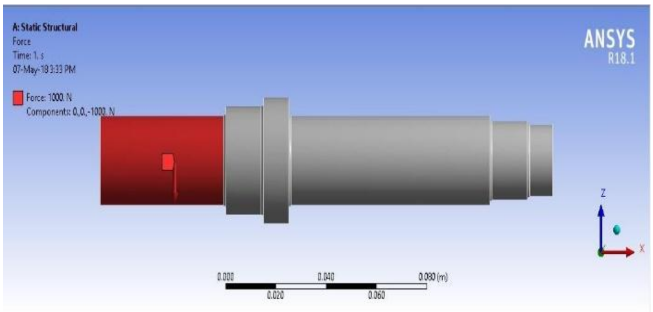

Figure 8: Load on flange of a regular shaft

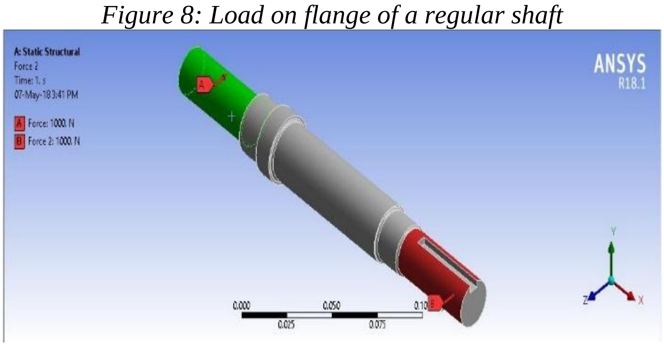

Figure 9: Load on bilateral flanges of an extended shaft

B. NORMAL LOAD (MAGNETIC PULL + ROTOR WEIGHT)

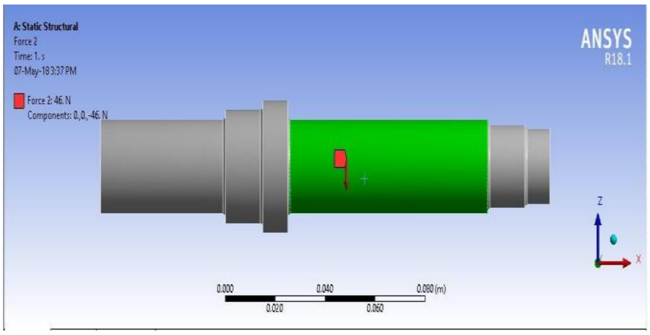

Figure 10: Normal load on regular Shaft

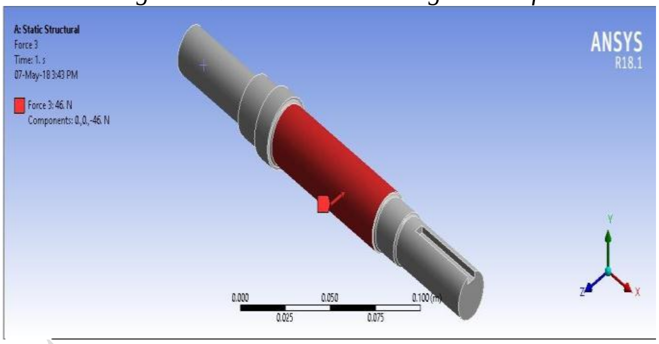

Figure 11: Normal load on extended Shaft

C. BEARING SUPPORT

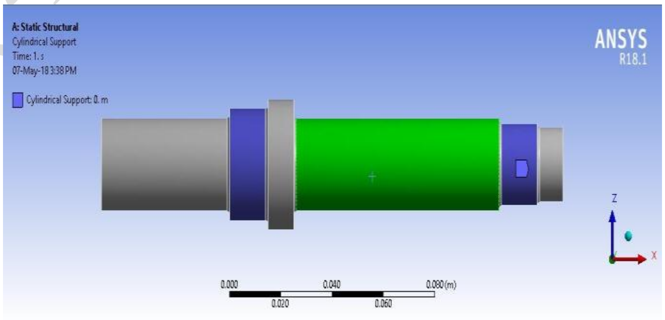

Figure 12: Cylindrical supports given to regular Shaft

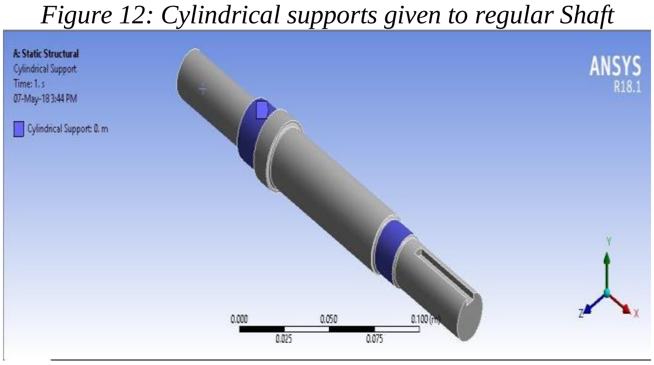

Figure 13: Cylindrical supports given to extended Shaft

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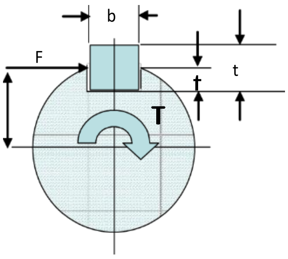
VII. CALCULATIONS

Structural Steel: FE410A	
Density	7859 kg/m^3
Tensile yield strength	240 Mpa
Tensile ultimate strength	465 Mpa
Compressive yield strength	250 Mpa
Strength co-efficient	920 Mpa
Young's Modulus	200 Gpa
Poisson's ratio	0.3003
Bulk Modulus	168 Gpa
Shear Modulus	77 Gpa
Grade	FE410A

Table 1: Material properties



T_m = 40,000 Nmm Max. Torque transmitted by the shaft (PMC6-030)

σ_y = 240 Mpa Yield S trength of the Shaft material (EN 24)

σ_{yk} = 323.7 Mpa Yield S trength of the Key m aterial (C40 Steel)

d = 20 mm Diameter of the Shaft Extension

b = 5 mm Width of Key (Size of key as per DIN 6885 part 1)

t = 4 mm Height of key (Size of key as per DIN 6885 part 1)

t_1 = 2.26 mm Keyway depth in shaft (Keyway depth as per DIN 6885)

n = 1 Number of keys

Nominal shear stress on shaft is

$$\tau n := \frac{\frac{Tm}{n}}{\frac{\Pi}{16} \times \left[(d - t1)^3\right]}$$

So Nominal shear stress on shaft key way is lesser than Yield strength of the shaft material. According to maximum shear stress theory, Maximum allowable shear stress in Shaft key way

$$\tau max := \frac{\sigma yk}{2.FOS}$$

τ_{max} = *29.972 Mpa*

$$L1 := \frac{\frac{Tm}{h}}{b \times \tau max \times \frac{d}{2}}$$

Considering Shearing failure, Length of key is *L1 = 26.69 mm*

Crushing strength,

$$\sigma ck := \frac{\sigma yk}{FOS}$$

σ_{ck} = *59.94 M pa*

$$L2 := \frac{\frac{Tm}{n}}{(t - t1) \times \frac{d}{2} \times \sigma ck}$$

Considering Crushing failure, Length of key is *L2 = 36.26 mm*

$$L := \begin{cases} L1 + b & \text{if } L1 > L2 \\ L2 + b & \text{otherwise} \end{cases}$$

Minimum Key length is *L = 41.26mm*

VIII. RESULT AND DISCUSSION

Ansys Mechanical finite element analysis software is used to simulate computer models of structures, electronics, or machine components for analyzing strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes.

A. EQUIVALENT STRESS

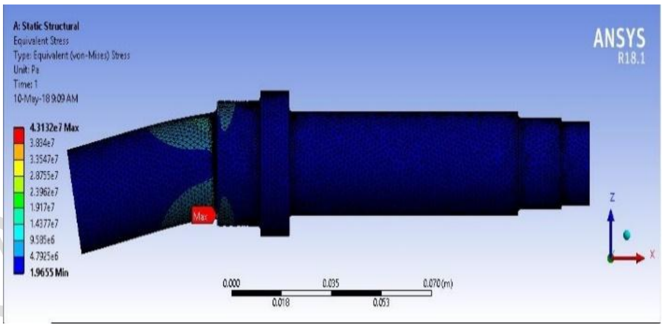


Figure 14: Equivalent stress in regular Shaft

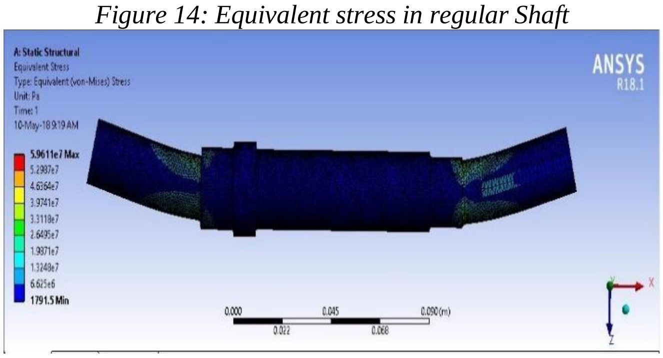


Figure 15: Equivalent stress in extended Shaft

Equivalent stress (or) von-mises stress

Extended shaft = 59.611 N/mm^2

Regular shaft = 43.132 N/mm^2

B. TOTAL DEFORMATION

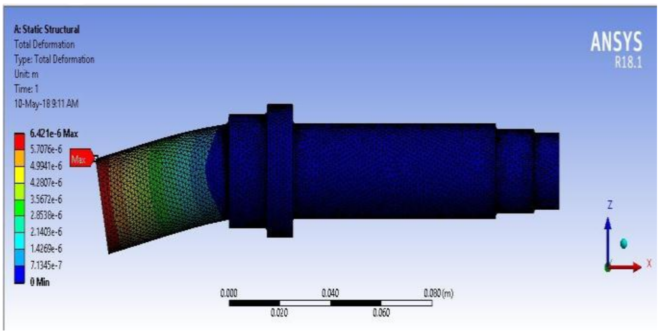


Figure 16: Total Deformation in regular Shaft

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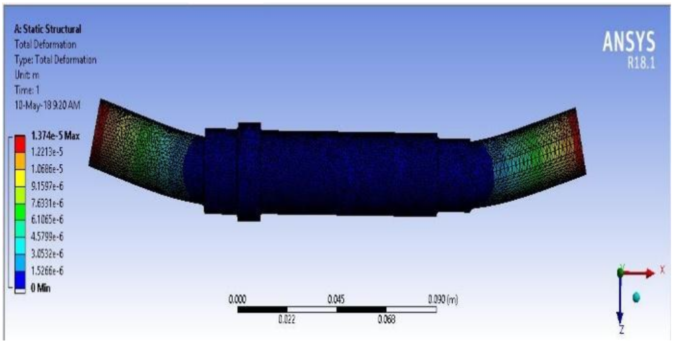

Figure 17: Total Deformation in extended Shaft

Deformation:

Extended shaft = 1.374 10^{-5} m

Regular shaft = 6.421 10^{-6} m

Given, Yield strength of shaft material = 240 N/mm^2

Maximum stressin regular shaft=43.132N/mm^2

Maximum stress in extended shaft = 50.611 N/mm^2

Factor of safety for regular shaft = 5.564

Factor of safety for extended shaft = 4.926

IX. CONCLUSION

From the above study, it is seen that there are many varieties in the shafts which are used for different applications, here the application is to carry out two works at the same time, by the same motor but with different location symmetric to the system.

By the comparison of standard shaft to the revised size customized shaft for multiple work gives the study answer as The load can be equally distributed on the both ends of the shaft when there is requirement of bi-sided rotational works‖. Even though it is having more applicability, the industries of rotary works only concentrating on this type of loads.

When we consider about the designing aspects and strength analysis by validation, calculations and also Ansys FEA method, the obtained factor of safety is 4.9 for the extended shaft.

Since the factor of safety is greater than 3.0 in standards, and for shafts should be more than that of 4.5, the structure (Extended shaft) is safe.

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