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Design analysis and optimization of a crankshaft of a tractor

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Abstract
This paper presents the design analysis of a crankshaft used in Pakistani made tractors. The finite element simulation techniques are utilized to analyze the crankshaft made up of chromoly steel. A two-dimensional static stress analysis is performed in ANSYS APDL to obtain von-mises stress that produced results which are significant to improve the component design at early development stage. Harmonic analysis is used to determine the steady state response to sinusoidal (harmonic) loads of known frequency. Modal analysis is carried out to determine the natural frequencies of the crankshaft and the mode shapes is examined.

Keywords: two-dimensional static analysis, von-mises stress, harmonic analysis, modal analysis

Introduction
Crankshafts are commonly used in power transmission devices with a wide range of applications from small one cylinder to very large multi-cylinder marine engines, [1]. Tractor industry using locally manufactured crankshafts in their engines needs to be updated in terms of design and analysis of engine components. Crankshafts manufactured locally do not have proper standards neither for selection of material nor for design calculations. An attempt is made through this work to present a design analysis of locally manufactured crankshaft. A survey was conducted regarding selection of crankshaft and Massy Ferguson MF-240, MF-350, MF-260 and MF-360 series was selected. All dimensions required for analysis were taken from sand casted locally manufactured crankshaft. A failure mode analysis of two damaged crankshaft was presented by M. Fonte [2]. One crankshaft was obtained from mini backhoe and other from automobile vehicle. A fatigue failure analysis was performed in this work. Luckjan Witak [3] also performed failure analysis of diesel crankshaft. In this work the recommendations for increase of the fatigue life of analyzed crankshaft were formulated. Amit Solanki [4] investigated stress variation over the engine cycle and the effect of torsion and bending load. Von-mises stress is calculated using theoretically and FEA software ANSYS. The relationship between the frequency and the vibration modal is explained by the modal and harmonic analysis of crankshaft using FEA software ANSYS. Jian Meng [5] analyzed crankshaft model and crank throw were created by Pro/ENGINEER software and then imported to ANSYS software. The crankshaft deformation was mainly bending deformation under the lower frequency. And the maximum deformation was located at the link between main bearing journal, crankpin and crank cheeks.

Modeling of Crankshaft
The dimensions were taken from locally manufactured crankshaft and CAD model was developed in Pro/E Wildfire 4.0 software. A crankshaft is modeled (fig. 1) for 3- cylinder engine (which is frequently used in tractors), however, only a single crank is modeled for analysis purpose due to symmetry (i.e. all the dimensions, boundary conditions, loadings, support distances, material are same).

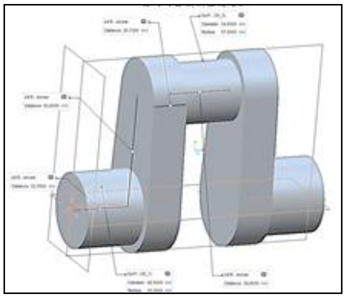

Fig 1: CAD Model of a Crankshaft

Analysis
The CAD model produced in Pro/E wildfire software is imported in ANSYS APDL (fig. 2) for analysis purpose. The following analyses are carried out in ANSYS APDL.

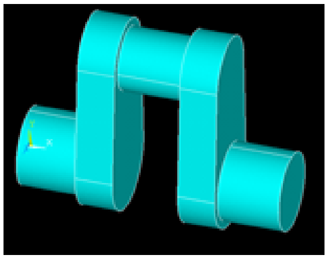

Fig 2: Crankshaft imported in ANSYS APDL

1. Static Analysis
Diesel engine crankshafts run with harmonic torsion combined with cyclic bending stress due to radial loads of combustion chamber pressure transmitted from the pistons and connecting rods, to which inertia loads from pistons and connecting rods have to be added, [6, 7]. The static analysis is performed for

obtaining the von-mises stress when the crankshaft is subjected to combined state of loading i.e. bending and torsion. Von Misses stress is widely used by designers to check whether their design will withstand a given load condition. Von Misses stress is considered to be a safe haven for design engineers. The crankshaft is meshed with solid 45 elements and constraints are applied. The deformed results are shown in fig. 3 and presented in table 1.

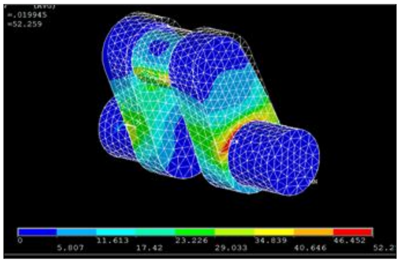

Fig 3: Deformation and Von-Mises Stress

Table 1: Results obtained from Static Analysis

Max. Deflection, mm	Von-Mises Stress, MPa	Factor of Safety (FOS)
0.019945	52.259	7.6

The recommended FOS for crankshafts is 3 so it is clear from analysis that the locally produced crankshafts are over-designed. To address this issue, two solutions are proposed.

Solution # 1

New material is should be used i.e. nickel-chrome steel. The allowable stress for nickel-chrome steel is 150 MPa that gives FOS of 3 which comes under recommended range.

Solution # 2

Use chromoly steel with modified dimensions. The modified dimensions are as follows:

- diameter of crankpin = d_C = 27 mm
- diameter of crankshaft = d_S = 33 mm
- thickness of the web = t = 18 mm
- width of the web = w = 43.1 mm
- length of crankpin = l_C = 35 mm
- length of the bearing = l_B = 33.7 mm

The crankshaft is again modeled in Pro/E wildfire software with modified dimensions and imported in ANSYS APDL for analysis purpose. The results obtained are shown in fig. 4 and presented in table 2. From table 2, it is clear that the design is safe.

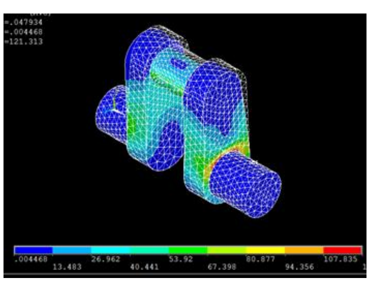

Fig. 4 Modified FEA Results

Table 2: Modified results obtained from Static Analysis

Max. Deflection, mm	Von-Mises Stress, MPa	Factor of Safety (FOS)
0.047934	121.33	3.3

2. Dynamic analysis

Crankshaft is analyzed for dynamic design by performing harmonic and modal analysis in ANSYS APDL.

2.1 Harmonic Analysis

Crankshaft is investigated under the dynamic force of piston transferred to crankshaft through connecting rod and gudgeon pin. This is shown in fig. 5 in term of graph between the amplitude and the frequency.

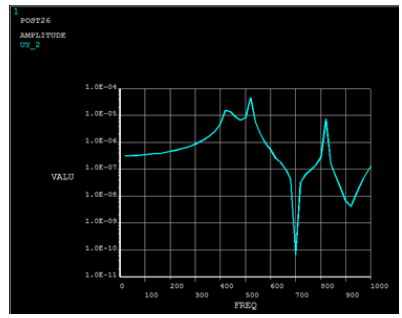

Fig 5: Frequency vs Amplitude

Harmonic response of the crankshaft for the excitation in the range of 0-1000 Hz is analyzed. Variation of displacement amplitude (frequency response) with respect to frequency is plotted graphically. The range of frequency starts from 0 Hz and lasts to 1000 Hz figures the maximum deformation at a frequency of 520 Hz at zero degree phase angle. Amplitude and the frequency diagram depict the various peak points of amplitude at different frequency points. The magnitude of amplitude of harmonic vibrations goes on changing at small intervals of frequency. The amplitude hikes at 500 Hz and 800 Hz becomes lowers at 700 Hz.

2.2 Modal Analysis

Modal analysis is the field of measuring and analyzing the dynamic response of structures. Modal analysis is performed in ANSYS APDL to find out mode shapes and resonant frequencies. The results obtained from simulations are presented in table 3.

Table 3: Resonant Frequencies

Mode	Deformation (*mm*)	Frequency (*Hz*)
1st	2.066	144.919
2nd	1.759	173.094
3rd	2.539	233.931
4th	5.38	2297

The results of modal analysis are extremely important as the resonance frequency or the frequency at which the effects of vibration are at peak is provided. The modal analysis also provides the starting point for harmonic and transient dynamic analysis where, the details of these mode shapes with their frequencies are useful.

Conclusion

Geometry optimization resulted in approximately 30% weight reduction of the crankshaft, which was achieved by changing the dimensions and geometry of the crank webs while maintaining dynamic balance of the crankshaft. This stage of optimization did not require any changes in the engine block or connecting rod. Using the nickel chromium instead of chromoly steel, there is a saving in overall cost of the crankshaft without changing the dimensions. Accurate stresses are critical input to fatigue analysis and optimization of the crankshaft. The stress obtained from the static analysis may be used in fatigue analysis of crankshaft. There are two different load sources in an engine; inertia and combustion. These two load source cause both bending and torsional load on the crankshaft. The result produced for static analysis gives von-mises stress for combined state of loading. Dynamic analysis reported amplitudes of vibration corresponding to different frequencies as well as modes of vibration and resonant frequencies for crankshaft. These results are very beneficial for the designers of crankshaft for tractors.

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