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Parametric Optimization of Four Cylinder Engine Crankshafts

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ABSTRACT: *The life of crankshaft is depends on its strength to wear stress and loads. So to increase the strength of crankshaft, there is need to change its parameter with its constraints. This paper aims at complete optimization of parameters. The parametric optimization has been done to increase the frequency it means the higher the frequency higher the stiffness or strength with optimum weight of the component.*

KEY WORDS: *Crankshaft, Mesh generation, Optimization, Parameters*

I. INTRODUCTION

Crankshaft is one of the most important moving parts in internal combustion engine. Crankshaft is a large component with a complex geometry in the engine, which converts the reciprocating displacement of the piston into a rotary motion. Crankshaft consists of the shaft parts which revolve in the main bearings, the crankpins to which the big ends of the connected rod are connected the crank arms to webs (also called cheeks) which connect the crankpins and the shaft parts. The crankshaft main- journals rotate in a set of supporting bearings (main bearings) causing the offset road journals to rotate in circular path around the main journal centers The complicated geometry of crankshaft and the complex torque applied by cylinders make their analysis difficult. But optimized meshing and accurate simulation of boundary conditions along with ability to apply complex torque provided by various FEM packages have helped the designer to carry torsional vibration analysis with the investigation of critical stresses.FEM enables to find critical locations and quantitative analysis of the stress distribution and deformed shapes under loads. The specific engine crankshaft of a major automobile company (the name is kept confidential) is taken as the model for the analysis.

Objectives: The project aims at detail FEM analysis of crankshaft. The following are the main objectives of the project.

[1] Building a 3-D Solid parametric model of crankshaft, Flywheel and pulley in Pro-Engineer wild fire.
[2] Meshing the model by Tetrahedral Solid 285 elements in Ansys. MPC 184 element is also used to define the journal bearings.
[3] The parametric optimization has been done to increase the frequency it means the higher the frequency higher the stiffness or strength with optimum weight of the component.

Crankshaft Vibrations: In I.C. engines various types of excitation forces exist. These directly or indirectly affect the crankshaft dynamics.

The major types of these vibrations are

• **Torsional vibrations**: shows spatial view of a 4-cylinder engine crankshaft. In multi cylinder engine crankshafts, the crank throws are spatial or out of phase with each other for the balancing purpose. It is also attached with a flywheel and some driven system. The torque is applied to the crankpin by the connecting rod. This torque is of varying nature because of variation in gas pressure and inertia forces. The fluctuating torque at the crankpin causes the twisting and untwisting periodically. Hence the torsional vibrations are induced.

• **Flexural vibrations**: The lateral periodic motion of crankshaft under the fluctuating forces exerted by connecting rod at crankpin cause bending vibrations of crankshaft. This mode shape generally has many nodes because the bending vibrations are strongly reacted at the bearings.

• **Axial vibrations**: The torsional vibrations can cause axial vibration in the twisting and untwisting motion. Also radial forces at crankpin cause some axial movement of crankthrow.

• **Coupled vibrations**: In general, however the various modes of vibration are coupled so that vibrations of one type can't occur without an accompanying vibration of the other type. These are not troublesome if there is considerable spread between the natural frequencies of the modes of vibration involved; i.e. the modes get weakly coupled.

1.3. Influence of Crankshaft Vibrations:
The crankshaft vibrations badly affect the working of engine.
The major areas are as follows.

[1] The torsional vibrations cause the angular velocities of all the cranks to vary but not in the same proportions. The crank away from the node has maximum effects compared to crank near the node. This affects the balancing.

[2] Due to same reason discussed above, stresses of varying intensity are generated in whole length of the crankshaft. These are also fluctuating in nature and hence cause fatigue of crankshaft, reducing its life. The stresses induced are dangerous at fillet or oil-hole locations.

[3] Vibratory energy is transmitted to all parts of the structure where it causes structural damage.

[4] It induces noisy operation of engine, which is undesirable in passenger cars. It also causes wear of all running parts.

II. SOLID MODELING OF CRANKSHAFT

As a prerequisite to the finite element model is the physical geometry of the part i.e. the suspension link we have created using Prove-Wildfire software.

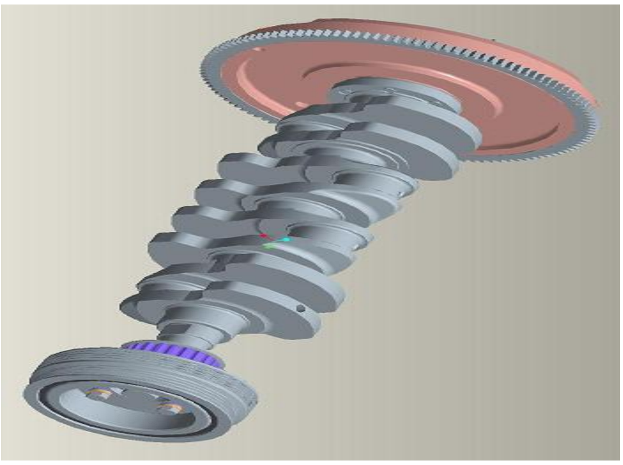


Fig 1. Solid Modeling of Crankshaft

III. MESH GENERATION

Meshing generally falls in two categories depending on the geometry of the element. For a 3D machine element of regular shape, solid meshing is sufficient, but for irregular geometries we have to first use surface meshing and then solid meshing. We have done surface meshing first by Solid 183 element. One of the important aspect in surface meshing is merging of nodes or technically it can be called node equivalence. Once the node equivalence is confirmed we have to go for free-edge checking which will ensure that there are no free surfaces. Now, after free surface check is done, we go for quality check, the quality check in Ansys is a unique feature as it allows us not only to check for internal and external angles of the mesh element but also facilitates in checking aspect ratio, warpage ratio, skew ratio, and most important the Jacobian matrix. The value of the Jacobian matrix should always lie between 0 and 1. Any other value of the Jacobian matrix renders the element faulty and a new element should be created by deleting the previous one. In our case the value of Jacobian matrix is 0.7 Once assured with a safe and sound surface meshing our next step is to import the model in ANSYS for solid meshing. The element used for solid meshing is *10 Node Solid 187 Tetrahedral Element*. The special features of this element are Plasticity, Creep, Swelling, Stress stiffening, Large deflection, Large strain, Birth and death.

MPC184: Multipoint Constraint Elements: Rigid Link, Rigid Beam, Slider, Spherical, Revolute, Universal
MPC184 comprises a general class of multipoint constraint elements that implement kinematic constraints using Lagrange multipliers. The elements are loosely classified here as “constraint elements” and “joint elements”. All

of these elements are used in situations that require you to impose some kind of constraint to meet certain requirements. The constraint may be as simple as that of identical displacements at a joint. They can also be more complicated, such as those that involve rigid modeling of parts, or kinematic constraints that transmit motion between flexible bodies in a particular way. For example, a structure may consist of some rigid parts and some moving parts connected together by some rotational or sliding connections. The rigid part of the structure may be modeled using the MPC184 Link/Beam elements, while the moving parts may be connected with the MPC184 slider, spherical, revolute, or universal joint element. Since these elements are implemented using Lagrange multipliers, the constraint forces and moments are available for output purposes. This element is used to define the connectivity between the point of application of force and the nodded on the surface of the structural member.

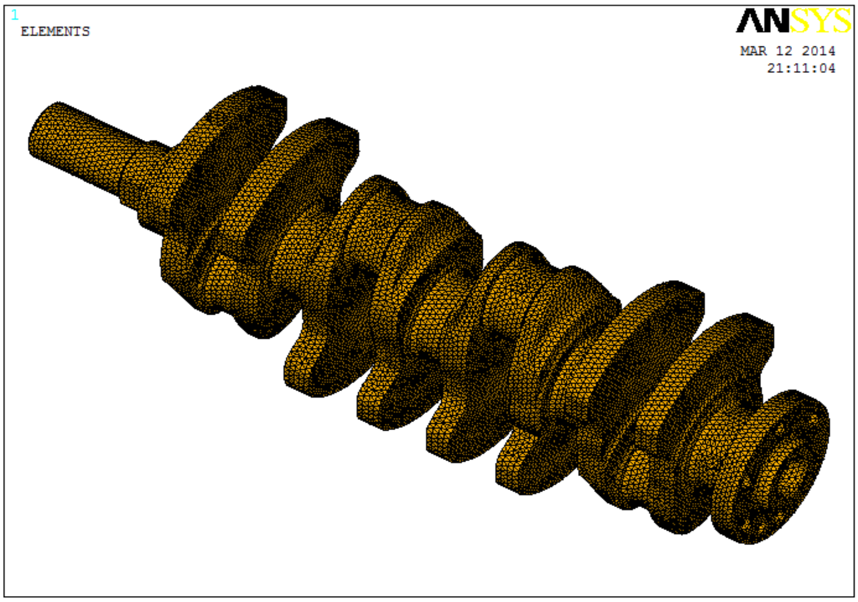


Fig 2. Meshed model of crankshaft

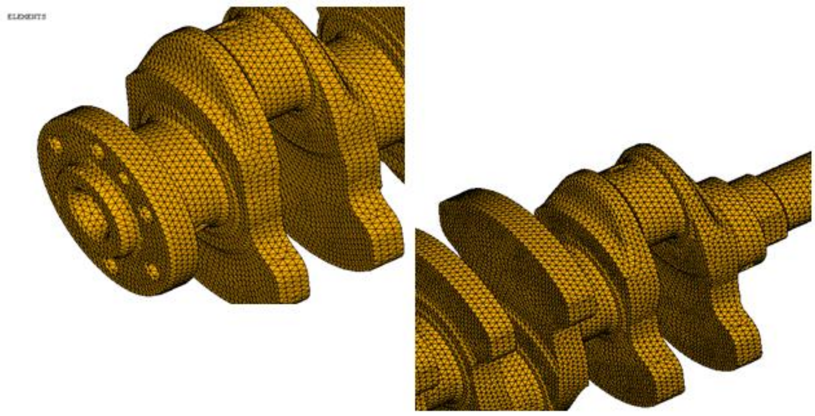


Fig 3. Enlarge view of dense meshed model

IV. PARAMETRIC OPTIMIZATION

To study the effect of different dimensional parameters on stiffness and frequency of the crank shaft. The parametric optimization has been done to increase the frequency it means the higher the frequency higher the stiffness or strength with optimum weight of the component.In Ansys the Optimization begins with building a parametric model of the initial design and creating an analysis file.

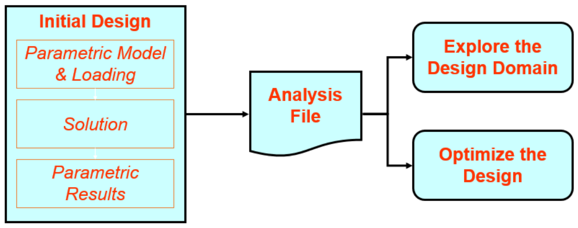


Fig.4 Steps of optimization in Ansys

There are four main steps (assuming that the analysis file is available):

a. Identify the analysis file
b. Identify optimization variables - DVs, SVs, and objective function
c. Run the optimization
d. Review results

The APDL programme has generated for input and parametric model and for optimisation solution steps

```
/PREP7
!Generate Volume1
D1=35 !Parameter1
D2=16 !Parameter2
L1=55 !Parameter3
L2=52 !Parameter4
C1=1.5
K,1,0,D2/2,,
K,2,0,D1/2-C1,,
K,3,C1,D1/2,,
K,4,L1,D1/2,,
K,5,L1,0,,
K,6,L2,0,,
K,7,L2,D2/2,,
L,1,2
L,2,3
!
!
/solu
!
/post1
!
!
!!!!!!!!!!!!!!!!! The Programme for optimization solution!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
/INPUT,'macro2','txt',
/OPT
SAVE
OPANL,'macro2','txt',' '
OPVAR,D1,DV,30,37, ,
OPVAR,D2,DV,12,17, ,
OPVAR,D4,DV,40,60, ,
OPVAR,L4,DV,20,24, ,
OPVAR,FREQ1,SV,0,350, ,
OPVAR,FREQ2,SV,0,550, ,
OPVAR,DFREQ,OBJ, , , ,
OPDATA, , ,
OPLOOP,TOP,IGNO,SCAL
OPPRNT,OFF
OPKEEP,ON
OPTYPE,SUBP
OPSUBP,5,3,
```

```
OPEQN,0,0,0,0,0,
OPEXE
! REVIEW RESULTS
oplist                    ! List all design sets
plvaropt,D1,DFREQ    ! Graph angles vs. set number
plvaropt,D1               ! Graph mid x-loc vs. set number
plvaropt,D2              ! Graph mid y-loc vs. set number
plvaropt,FREQ1              ! Graph max hoop stress vs. set number
plvaropt,FREQ2             ! Graph frequency vs. set number
plvaropt,D1,D2,FREQ1,FREQ2,D4,L4,DFREQ              ! Graph total volume
Finish
```

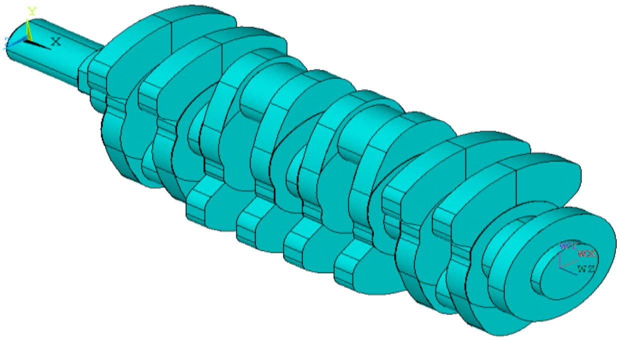
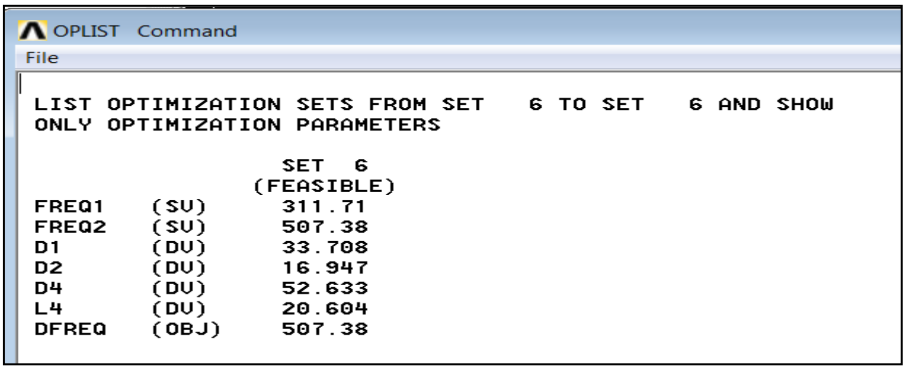


Fig.5 Parametric model generated by APDL programme



OPLIST Command
File

LIST OPTIMIZATION SETS FROM SET 6 TO SET 6 AND SHOW
ONLY OPTIMIZATION PARAMETERS

		SET 6 (FEASIBLE)
FREQ1	(SV)	311.71
FREQ2	(SV)	507.38
D1	(DV)	33.708
D2	(DV)	16.947
D4	(DV)	52.633
L4	(DV)	20.604
DFREQ	(OBJ)	507.38

Fig.6 List of the best feasible optimization set

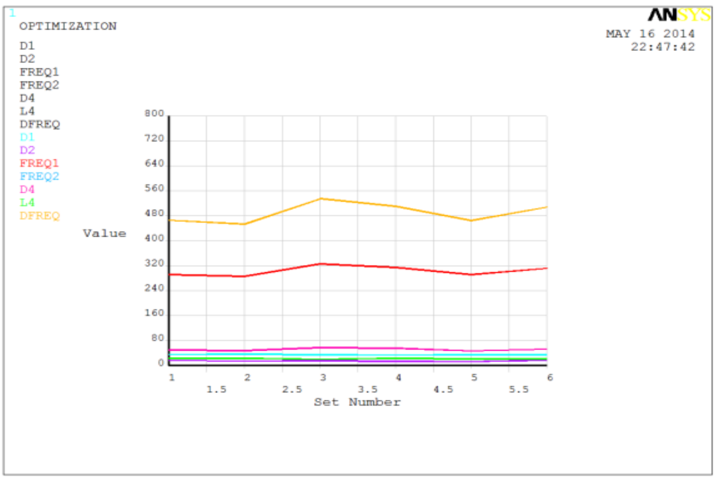


Fig.7 The parameters variation with optimization

The below is the optimum mass and volume after the parametric optimization

```
SUMMATION OF ALL SELECTED VOLUMES
    TOTAL VOLUME = 0.16826E+07 mm3
    TOTAL MASS   = 0.13209E-01 in Tones
    CENTER OF MASS:  XC= 234.12      YC= 0.0000      ZC= 0.0000

                   *** MOMENTS OF INERTIA ***

       ABOUT ORIGIN     ABOUT CENTER OF MASS    PRINCIPAL
   IXX =     21.775          21.775             21.775
   IYY =     857.70          133.71             133.71
   IZZ =     868.89          144.90             144.90
   IXY =   -0.24706E-04     0.44850E-05
   IYZ =   -0.91886E-07    -0.91885E-07
   IZX =   -0.19755E-05     0.22381E-04
```

Fig.8 Optimum mass and volume

The best feasible set is set number 6 which indicates the best optimum dimensions i.e. D1, D2, D4 and L4. The above Figure indicates there is not much effect of dimension D1 on frequency.

V. Discussion And Conclusion

- Normally in every crankshaft the problem is at the fillet area at the end, keeping all geometrical parameter of crankshaft variable to get optimize geometrical, we studied that higher the frequency higher the stiffness as frequency is directly proportional to stiffness and inversely proportional to mass. So by reducing mass and increasing stiffness we can get the maximum stiffness.

VI. FUTURE SCOPE

- Mashed model can be used for type of analysis like thermal loading, fatigue analysis, mechanism analysis etc.
- In Future parametric optimization can be done by changing other parameters of crankshaft.

VII. ACKNOWLEDGEMENT

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