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Economical crankshaft design through topology analysis for C type gap frame power press SNX-320

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ABSTRACT

Introduction. The presses are powered machines having stationary beds and slides (rams) which have controlled sliding motion towards and away from the beds, guided by the frames. Metal can be worked in power press in a wide verity of ways like punching, shearing, forming, etc. Crankshaft is one of the basic components for power transmission, which transmits rotary motion to sliding motion in the mechanical power press. It is around this element that all stresses and deformations are concentrated. **The purpose** of the study: rationalization of the design of the crankshaft, taking into account the strength characteristics of the frame, connection screws, tie rods. **The methods** include two stages of crankshaft design development: 1) modelling in parametric cad software; 2) *FE* analysis in *Ansys-22R1*. The existing as well as the improved design of the crankshaft was investigated by the *FE* method with topology analysis. Topology is part of *FE* analysis as well as *Generative design*. **Result and Discussion.** The design of the crankshaft, including the bearing assembly, depends largely on the maximum pressure that will be generated at the bottom of the stroke, and this is carefully considered when designing other parts of the presses. Based on the results of the topology analysis of the crankshaft structure, it was found that an increase in the strength of this structural element is possible by adding additional material in the area of potential destruction. During the study, it was possible to develop a rational design of the crankshaft with improved mechanical properties compared to the existing one, which will increase the service life of the crankshaft, preventing its failure.

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Introduction

The presses are powered machines having stationary beds and slides (rams) which have controlled sliding motion towards and away from the beds, guided by the frames. Metal can be processed in a variety of ways with the help of mechanical presses. There are usually several methods of performing any operations that might be required for given piece [1–4]. Presses have long been used in almost all areas of activity

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related to the processing of various materials in a cold or hot state: pressing, crushing, shaping, coating, expanding. In any case, due to the technological properties of metals and its wide range, a wide range of technological operations can be applied to it [4].

Stroke length of the power press depends on the eccentricity of crankshaft. Fig. 1 shows the complete nomenclature of the power press [1].

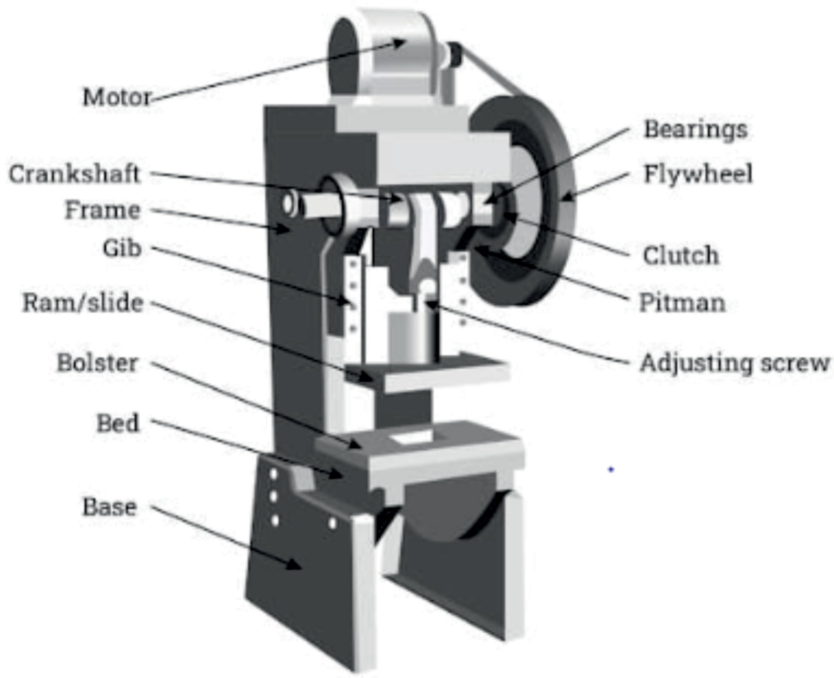

Fig. 1. Press machine arrangement

It is used for fast, accurate and economical production of a large number of products by cold working mild steel and other ductile materials. Presses are classified according to the numbers of actions (single, double, triple action etc.), die operation direction (vertical, horizontal, oblique, etc), the kind of power used to operate the dies (mechanical or hydraulic), and mechanism used to drive the dies (crank, knuckle, friction, screw, link, etc [2].

The crankshaft may be called the heart of the press. It is around this member that all stresses and strains are concentrated. The strength of the frame, connecting rod, tie rods and other vital parts are based on the capacity of the crankshaft.

The design of the crankshaft, including the location of the bearings, is largely dependent on the maximum pressure that can be generated at the bottom of the stroke, as shown in fig. 2. Standard crankshafts are made of carbon, chromium-manganese, chromium-nickel-molybdenum and other steels, as well as special high-strength cast irons. After stamping, before machining, the shaft blanks are subjected to heat treatment. For a heavily loaded shaft, the following maintenance modes are usually used: normalization, hardening + high tempering (improvement).

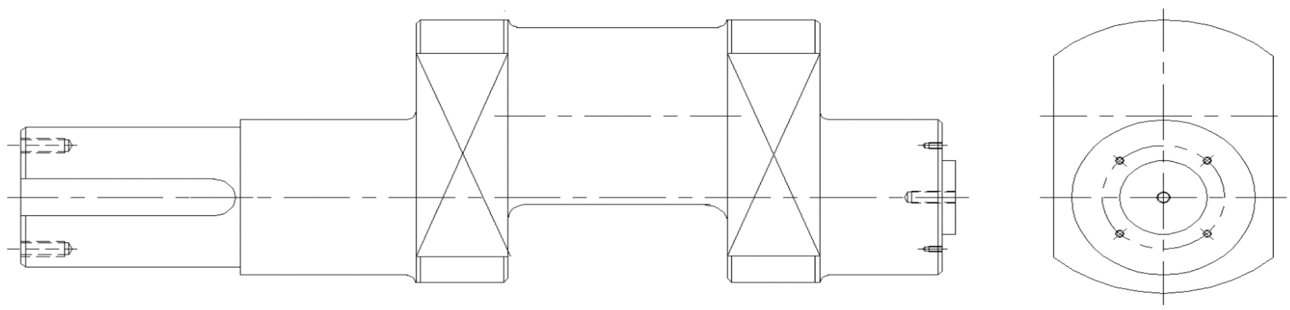

Fig. 2. Crankshaft layout

The tensile strength and elastic limit of the shaft in some cases can be considerably increased by a special heat-treating process. Special grades of steel having a greater elastic limit than standard shafts can also be used. However, heat treating or special steels are not necessary in most cases. Whenever used, it must be with the greatest caution as heat treating or special steels frequently bring the strength of the crankshaft above that of the other parts.

Research methodology

All studies of the crankshaft design were divided into two stages of development of this structural element: 1) 3D-modelling using computer-aided design systems; 2) analysis by the finite element method in the *Ansys-22R1* software. The existing as well as the improved design of the crankshaft was investigated by the Finite Element Method *(FEM)* with topology analysis. Topology is part of the *Finite Element Analysis* (*FEA*) as well as *Generative Design*, i.e. technology in which 3D models are created and optimized using cloud computing and artificial intelligence [2–14]. Any physical phenomenon such as the behaviour of structures or fluids, heat transfer, wave propagation, the formation of biological cells, etc. should be fully understood and quantified through mathematics. Partial differential equations (*PDEs*) are often used to describe most of these processes. However, over the past few decades, numerical methods have been developed to allow a computer to solve these *PDEs*. One of the best known numerical approaches is *FEA*.

FEM is a numerical method used in *FEA* that simulates any given physical state. Engineers use *FEA* software to accelerate the development of better products while reducing costs by minimizing the need for physical models and field experiments, and optimizing components during the design process.

Results and Discussion

Finite element analysis of existing crankshaft using Ansys22R1

According to the precise 2D drawing, an objective 3D parametric geometry of the crankshaft of a mechanical power press was created using a *CAD* (computer-aided design) system, such as the *Pro/Engineer* software package. This solid geometry has been imported in *.STEP* format for use in structural modelling of an existing project. Currently *Singhal Power Presses Pvt. Ltd.* collects data on the design of the crankshaft of a mechanical press in this format. To create the model shown in fig. 3, *Creo-5.2* was used, which allows creating files according to the *.STEP* standard [15–18].

The highlighted region in fig. 4 shows the results of the overall deformation after applying a force of 320 tons to the centre of the crankshaft. The maximum deformation occurs in the middle of the crankshaft, where a load of 320 tons acts and the deformation value is 0.050 mm, while the deflection in the bearing area is practically 0 mm.

Fig. 5 shows the equivalent stress in the corners near the crankshaft web under a load of 320 tons with a maximum value of 162.05 MPa and a minimum value of 9.64 MPa in the bearing area.

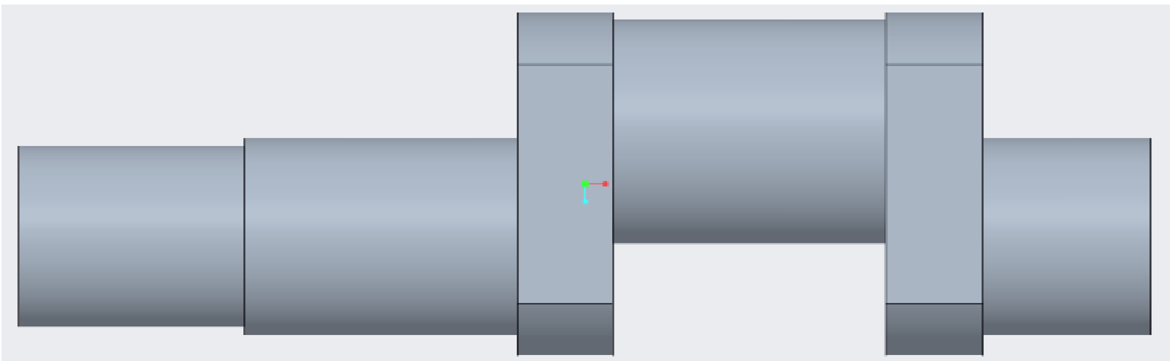

Fig. 3. Existing design of crankshaft

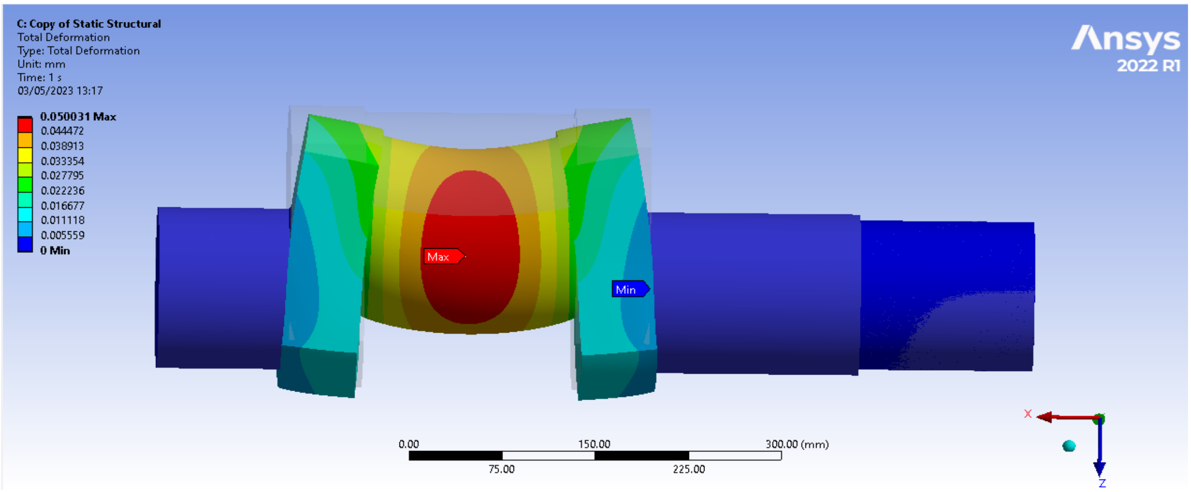

Fig. 4. Total deformation of existing crankshaft

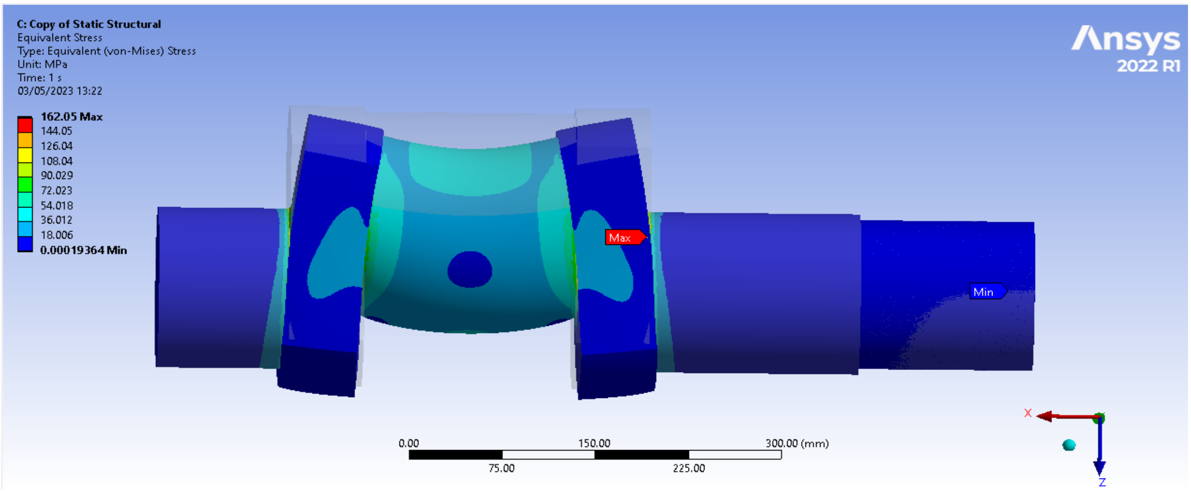

Fig. 5. Equivalent stress of existing crankshaft

From fig. 6, it is obvious that when a load of 320 tons is applied, the crankshaft experiences the greatest tension, while the maximum shear stress is 93.008 MPa, and the minimum shear stress is 0.106 MPa.

The crankshaft bearing area experiences maximum stress when a load of 320 tons is applied (fig. 7). The maximum principal stress here is 132.01 MPa and the minimum principal stress is –58.67 MPa, causing negative stresses on the end face (Table 1).

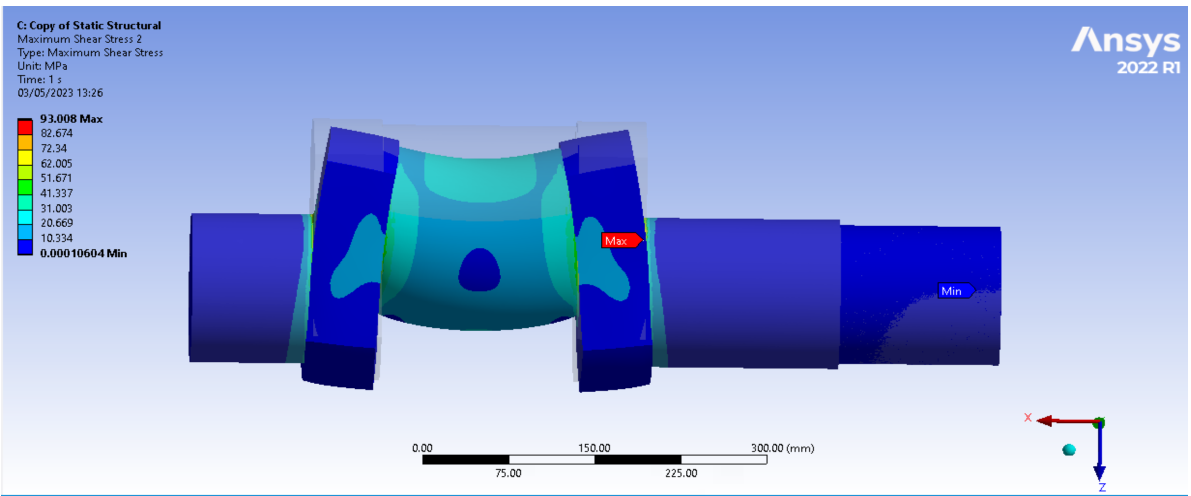

Fig. 6. Maximum shear stress in existing crank shaft

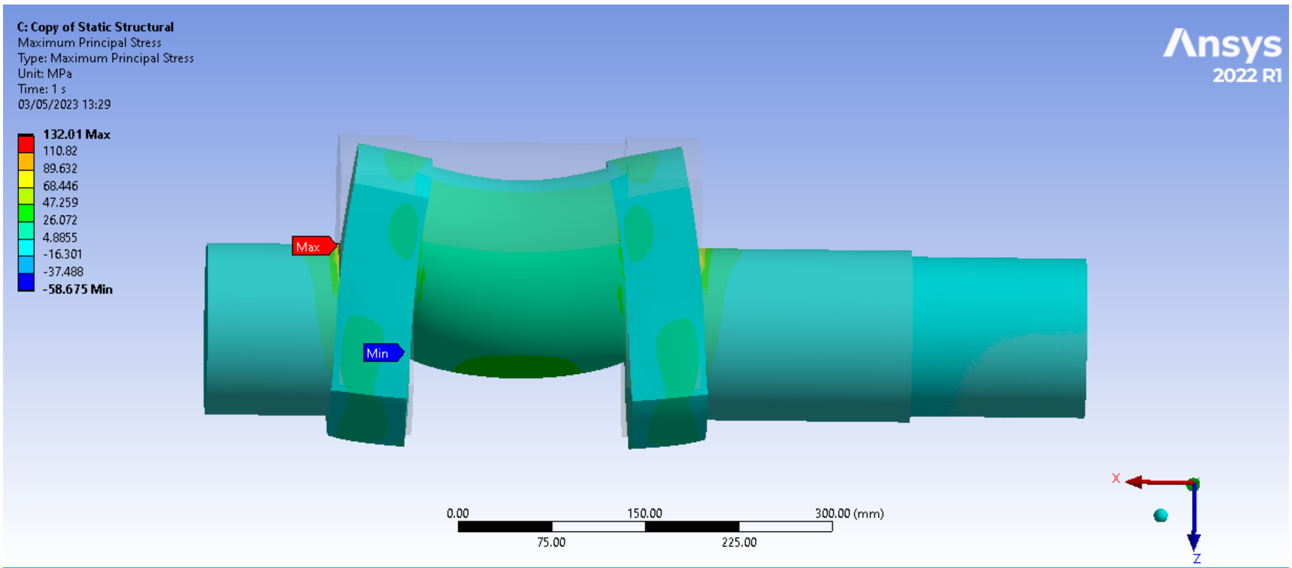

Fig. 7. Maximum principal stress in existing crankshaft

Table 1

Structural analysis results of existing crankshaft

Total Displacement, mm	*Von-Mises* Stress Theory, MPa	Max Principal Stress, MPa	Max. Shear Stress, MPa
0.050	162.05	132.01	93.00

Finite element analysis of optimized crankshaft using Ansys22R1

It is obvious that almost every component of the kinematic chain in the assembly, for which topological optimization has not been carried out, is overweight. The additional weight of structural elements leads to the use of excess material, which is the reason for the formation of excessive loads on moving components, reducing energy efficiency and increasing transportation costs [19–25]. And thanks to *Topological Optimization technology* (*ANSYS Mechanical*), there is a tool one needs to design strong and lightweight structural elements, regardless of its application. Targets can be easily defined and controls applied to ensure that manufacturing requirements are met, minimum material thicknesses are set, and exclusion areas are defined [26–29].

Topology optimization in *ANSYS Mechanical* allows:

1) taking into account multiple static loads in combination with optimization of natural frequencies (*modal analysis*);

2) meeting minimum material thickness requirements;

3) observing the rules regarding the direction of basing (installation) of the element (for example, for machining operations);

4) obtaining the possibility of implementing both cyclic and planar symmetry.

The highlighted region in fig. 8 shows the results of the total deformation after applying a load of 320 tons to the centre of the crankshaft. The maximum deformation occurs in the middle of the crankshaft, where a load of 320 tons is applied, and the deformation value is 0.046 mm, but the deflection in the bearing area is practically 0 mm.

Fig. 9 shows the equivalent stress at the end surfaces of the crankshaft. When applying a load of 320 tons, the crankshaft experiences the highest stresses on the end surfaces with a maximum equivalent stress of 191.24 MPa; in this case, the minimum equivalent stress occurs in the bearing area and is equal to 11.64 MPa.

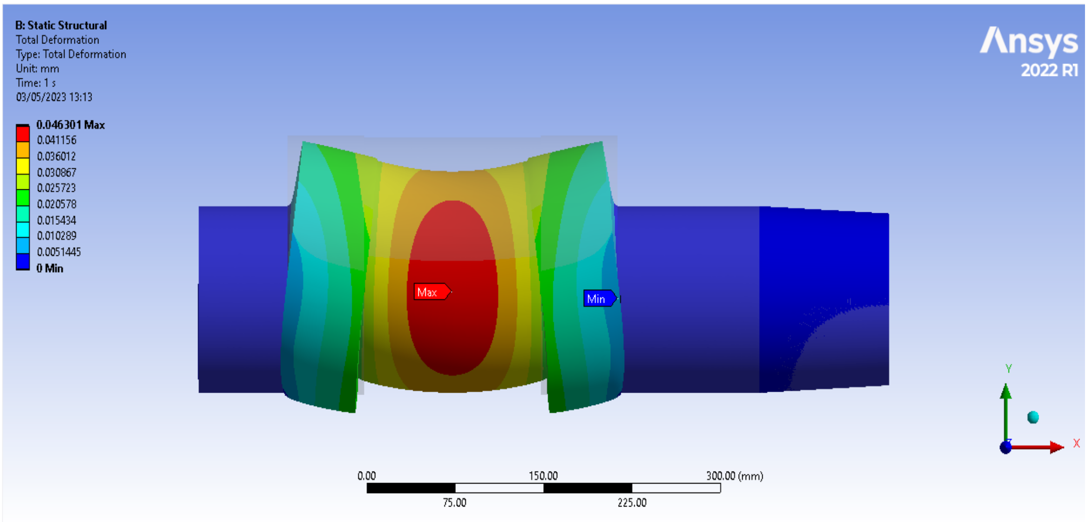

Fig. 8. Total deformation of optimized crankshaft

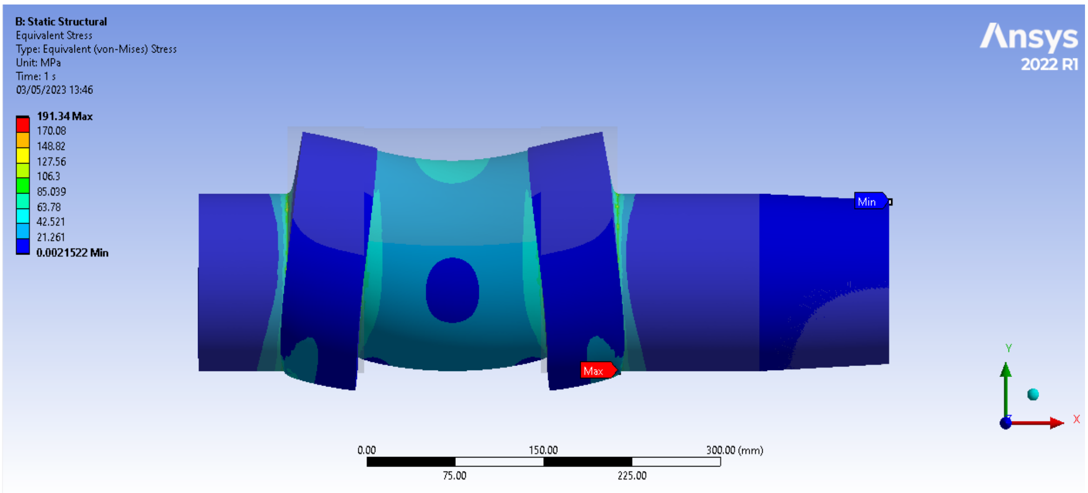

Fig. 9. Equivalent stress in optimized crankshaft

When a load of 320 tons is applied, the crankshaft bearing area experiences maximum stress (fig. 10). The maximum principal stress at this location is 189 MPa and the minimum principal stress at the end face is –11.27 MPa, causing a negative stress.

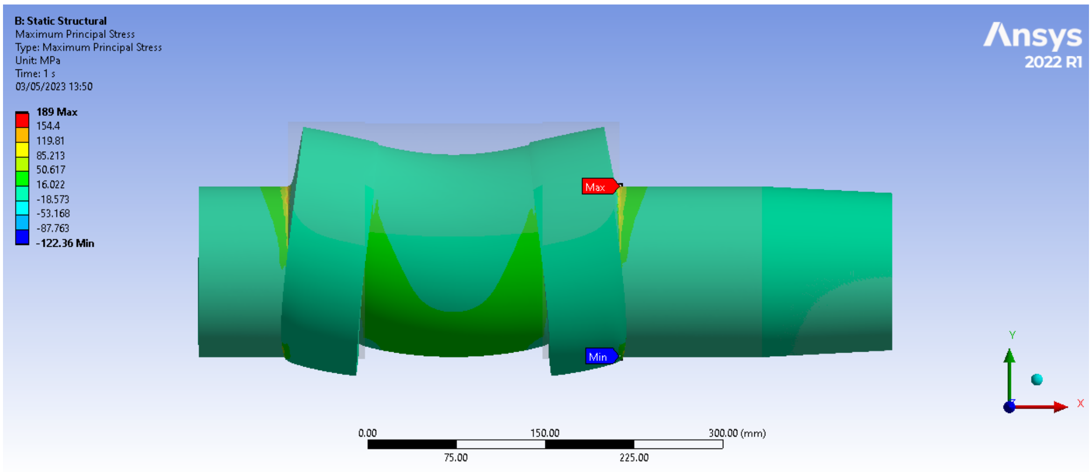

Fig. 10. Maximum principal stress in optimized crankshaft

From fig. 11 it is clear that the maximum stresses occur at the corner of the crankshaft when a load of 320 tons is applied, with the maximum shear stress is 98.124 MPa and the minimum shear stress is 0.2156 MPa.

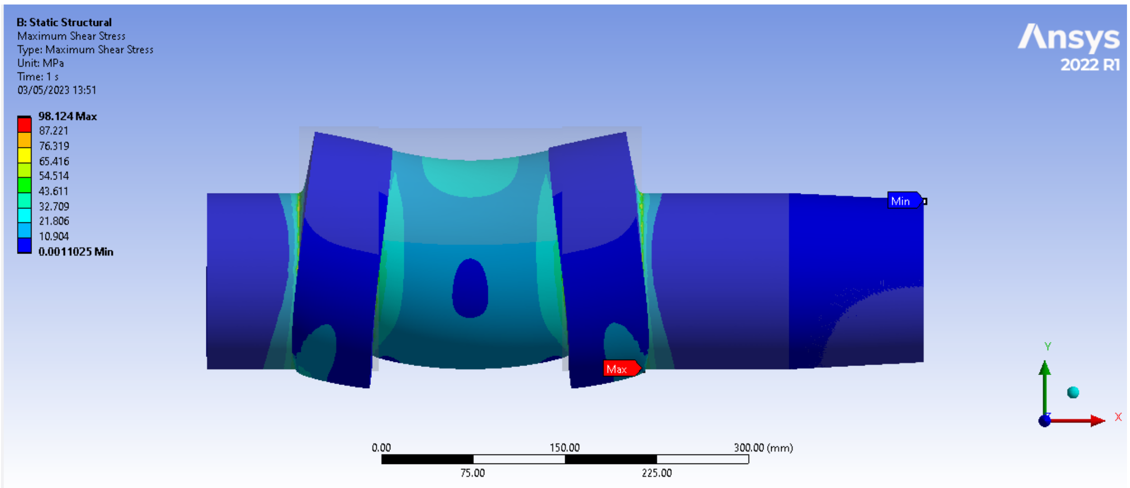

Fig. 11. Maximum shear stress in optimized crankshaft

Table 2

Structural analysis results of optimized crankshaft

Total Displacement, mm	*Von-Mises* Stress Theory, MPa	Max Principal Stress, MPa	Max. Shear Stress, MPa
0.0463	191.34	189	98.124

Table 3

Comparison of the existing and optimized crankshaft

	Existing crank shaft	New developed crank shaft	Percentage wise Improved results
Total Displacement	0.050 mm	0.0463 mm	7.45 %
Von-Mises Stress Theory	162.05 MPa	191.34 MPa	15.30 %
Max Principal Stress	132.01 MPa	189 MPa	30.15 %
Max. Shear Stress	93.008 MPa	98.124 MPa	5.21 %

Conclusion

From the results obtained by the Finite Element Method both for the existing design of the crankshaft and for the optimized one, it can be concluded that the optimization of the design of the crankshaft of a mechanical press leads to an increase in its performance in terms of reducing the bending deviation by 4 µm compared to the previous design. In addition, according to Table 3, the optimized crankshaft design shows improved *von Mises* results of 15.30 %, maximum principal stress of 30.15 %, and maximum shear stress of −5.21 %.

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Conflicts of Interest

The authors declare no conflict of interest.