JOURNAL OF ENGINEERING annals OF FACULTY OF ENGINEERING HUNEDOARA
Tome V (year 2007), Fascicole 2, (ISSN 1584 – 2665)

DESIGN OF CRANK SHAFT FOR A BRIQUETTING PRESS

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Abstract:
In recent years we have noticed sustainable increasing interest for biomass and energetic waste disposal. Our department has already for the past couple of years intensively focusing on the development of new machineries for waste disposal. One of them is the briquetting press BL 50-250. This article is dedicated to designing problems and the operation of a crank shaft for this press.
Keywords: machineries, waste, briquetting press,

1. BL 20-250 BRIQUETTING PRESS

The department of production engineering at the Faculty of Mechanical Engineering of the Slovak University of Technology in Bratislava has in 1996 developed a briquetting press BL 50-250. It is a mechanism intended for the compaction of solid waste without additional substances, into the state and shape suitable for transportation, storage, resp. energetic valuation. The machine is based on the principle of pressing in an open chamber with a piston and pressing orifice. It allows to achieve a very hard briquette with a density 1÷1,4 kg.dm^{-3} with possible length regulation (requirement [9], [10]).

Fig. 1 Briquetting press BL 50-250

Modular structure of the machinery also allows change of diameter of the briquette in the range of (50÷70) mm. The output of the press ranges from 250 to 350 kg.h^{-1} depending on the type of pressed material and the diameter of final briquette.

2. CRANK SHAFT OF THE BRIQUETTING PRESS

The crank shaft of the briquetting press BL 50-250 is cyclically loaded by a pressing force F_L (Fig. 2) which depends on the diameter of pressing piston and the pressure in the pressing chamber. From available literature, the value of pressure in the pressing chamber during general operation of the press is in the range between 90÷200 MPa. The pressure in the chamber depends mainly on the pressed area, type and properties of material to be pressed.

When working on the constructional design of the crank shaft we have to know the pressure in the pressing chamber. An often occurred problem is that this value is very difficult to measure. Therefore we often use estimations, theoretical calculations, resp. value of pressure needed to achieve a certain density of the briquette [1], [2]. Though we do not know real pressures. The second problem that arises is that of peak – breakdown pressures, where these values might several times overcome nominal values of the pressure. The radius of the crank shown on Fig. 3 is 60 mm, i.e. the crank assures a stroke of the pressing piston 120 mm. Typical revolutions of the crank shaft are 308 min^{-1}.

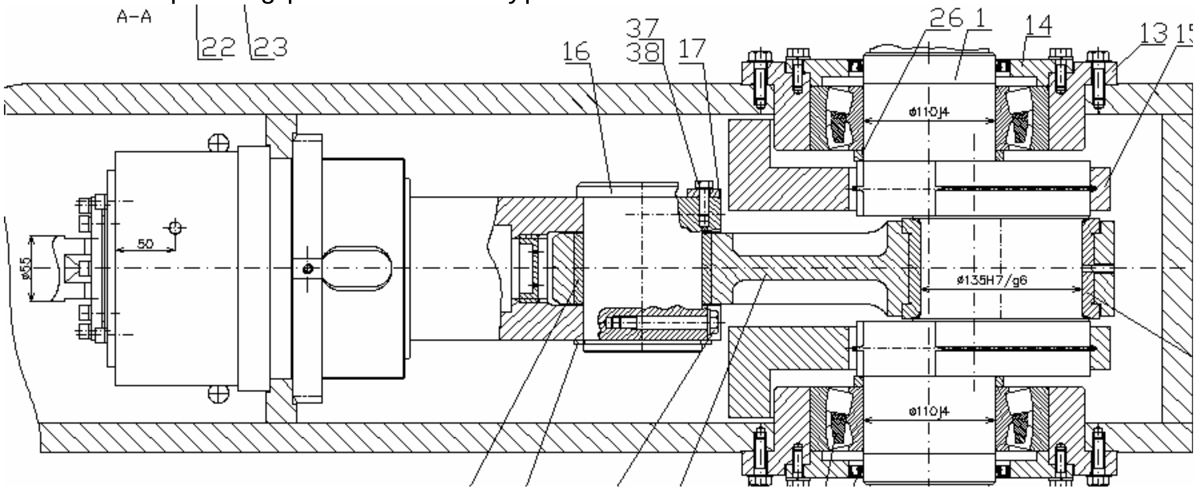


Fig. 2 Assembly of crank shaft press BL 50-25


Fig. 3 Crank Shaft of the BL 50-250 press

Because of the above conditions, the crank shaft can initiate a fracture which will consequently grow. At the same time the fracture itself can develop even later on. As an illustration we can show that during the design of the BL 50-250briquetting press [3] we performed resistance calculations of the crank shaft according to [4]. Later we will show that the safety ratio in the depicted critical cross-sections of the crank are from the shown press with a 50 mm diameter pressing chamber, a pressing force of 236 kN (which corresponds to a pressing pressure of 120 MPa).

3. DESIGNED CONSTRUCTION OF A CRANK SHAFT

The crank shaft of the BL 50-250 briquitting press is manufactured according to the drawing on Fig. 4. When designing the crank shaft on Fig. 4 we used our basic experience from the long running of the BL presses. In the fabrication of the shaft, many improvements where made which we will explain in the forgoing text. The semi product used for the fabrication of the shaft was a free forging with a cylindrical shape that was worked to the wanted shape according to the drawing.

For the manufacturing of the shaft many materials where used such as:

16 420.2 which was cemented, quenched and twice tempered. The cemented surface thickness was 0,9 mm. This material over time was abandoned, due to the limited about of cementite. Further because of deformation after cementation and quenching followed by machining at the manufacturer, this procedure in making this shaft proved to not guarantee acceptable quality and dependability. Thus the next logical material to replace this one was 14 220, resp. 15142.

15 230 quenched and tempered steel followed by nitrating. The disadvantage of this technology was that some of the nitrated sections were too thick. The thickness of a nitrated surface is 0,3 mm at a nitrating time of 35 hours. The resulting nitrated and then tempering contributed to large thermal deformations of the shaft. During the finishing operation, due to the deformation after nitrating and quenching it is necessary to machine a large fraction of material, this is quite undesired as we are actually machining the wanted hard nitrated surface.

With regards to the above mentioned problems we selected the material defined as **15 230** and manufactured the crank shaft using the following procedure: after rough machining of the forging it is suggested to quench the material to R_m=1000 MPa (40 HRC), this will guarantee sufficient strength with maintained core toughness. After quenching, the semi product is machined with large grinding surfaces. Then the shaft is carburized to a thickness of 0,07 mm. This creates a very thin, hard, brittle and impact resistant surface that is needed of the shaft mainly due to the roller bearings. Carburization is the final manufacturing operation, which is then followed by subsequent machining.

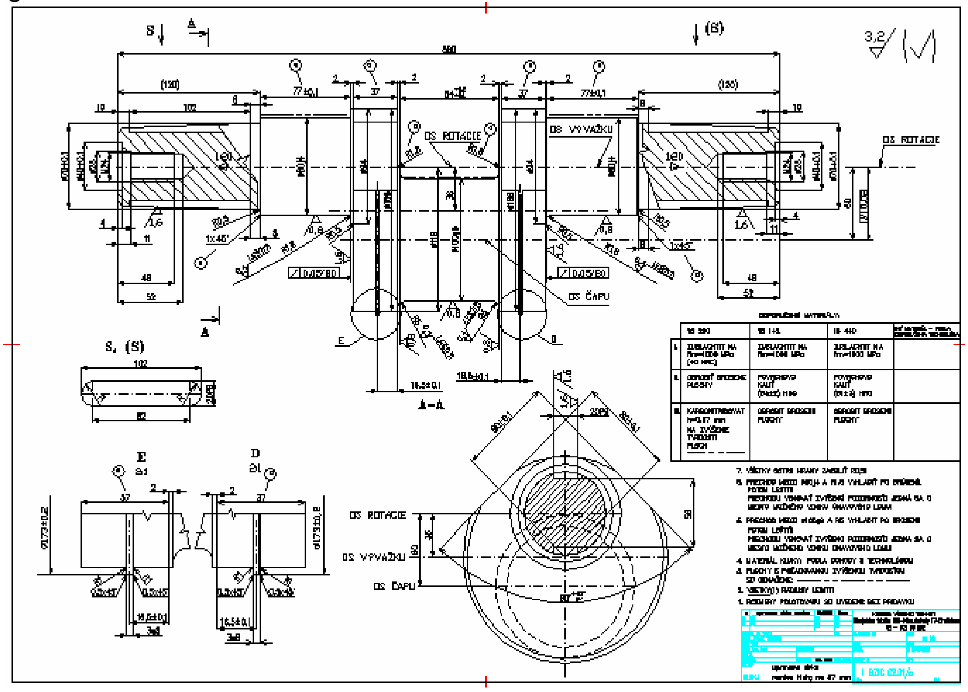


Figure 4. Výrobný výkres kľukového hriadeľa briketovacieho lisu BL 50-250

4. DEFECTS OF CRANK SHAFTS

The constructional design of the crank shaft and its strength calculation are very important tasks that need special attention. Despite that, even a correct constructional design of the crank shaft will not always prevent possible failure or break-down of the machine. Failures are often not able to be pre-indicated and they do not depend only on the correct constructional design or technological procedure of the production. This situation occurred in case of break-down of three briquetting presses of type BL caused by breakage of the crank shafts. In the first case it was a failure of two from three machines operated by one producer of briquettes. The second break-down occurred on a BL press installed at a foreign producer. This is a serious motive to again analyze the constructional design of crank shaft.

5. EXPERT ANALYSIS

5.1. Metallographic analysis of the fracture

The metallographic analysis showed the reasons for break-downs. In case of the first break-down it is from the view of the fracture area (Fig. 5) visible, that failure of the shaft according to [5] has been caused by the fatigue mechanism.

The machine has been permanently overloaded during its operation caused by inappropriate operation. The owner did not follow recommended operational parameters of presses and has been briquetting wooden waste of larger permitted fractions for this type of press. The next factor that had an important influence was the incorrect constructional solution of the crank shaft – small neck width of the crankshaft web (29 mm) and mainly the neck F as the strength raiser (Fig 6a). The side view shown on Fig. 6b shows that the neck of the crankshaft web, used for fixing balancing disks too much attenuated the crank. This neck was within the constructional changes adjusted in order to strengthen the crank as shown on Fig. 4.

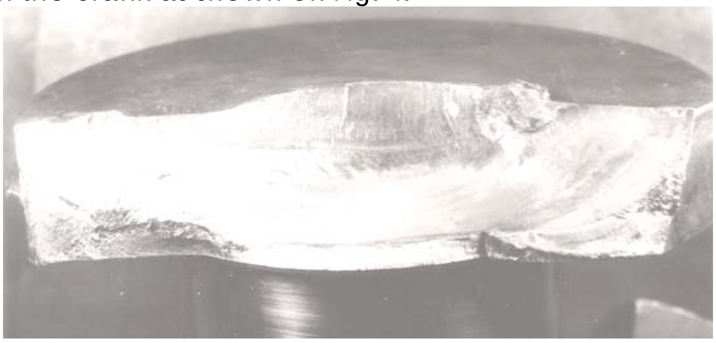
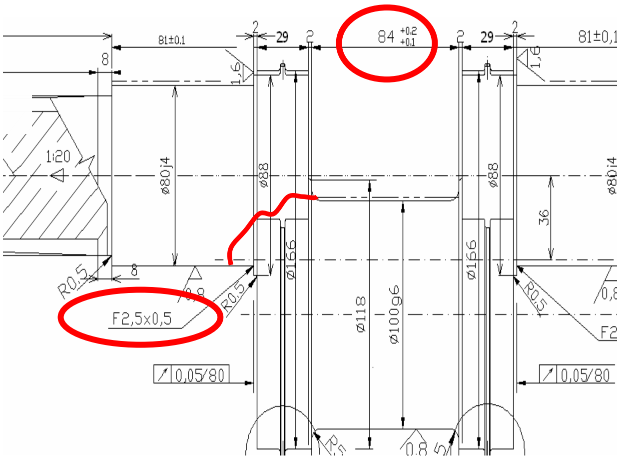


Fig. 5. Fracture area of the crank shaft at the first break-down (analysis ZTS MATEC, 27.1.2000)



a) b)

Fig. 6. Detail of crank shaft from the first break-down denoting the notch and possible construction causes

In the second case of break-down we found [6], that it had not fulfilled standard requirements concerning prescribed material for crank shaft production. The producer changed the standard material of the shaft of type 15 330 for type 15 142, as well as used inappropriate technology for its thermal processing.

Fig. 7. Fatigue fracture of the material

On Fig. 7 we can observe fatigue fracture of the material. Shiny and white areas (visible in the picture) were impaired even before fracture of the crank shaft. The overall view on the fracture surface shows that the cross-section of the material which has not been able to transmit the loading was approximately 30% smaller. Dark areas shown in Fig. 7 represent area of brittle impairment (break-down fracture).

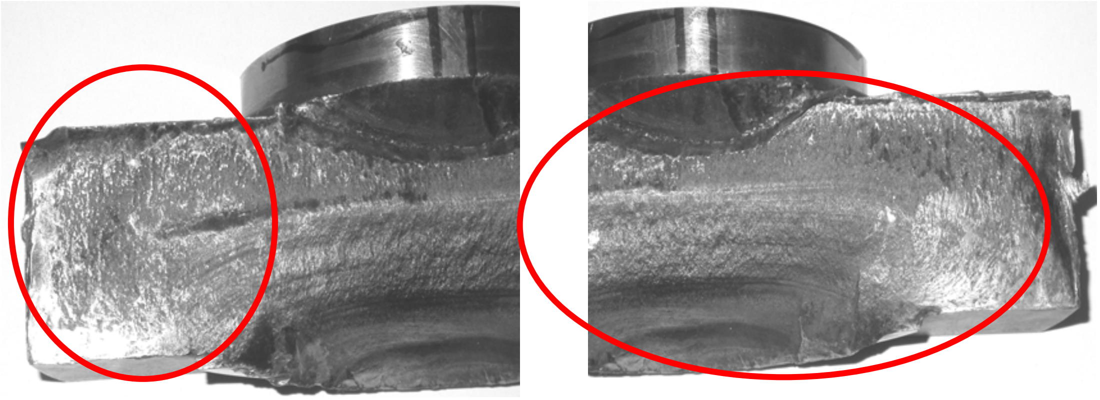
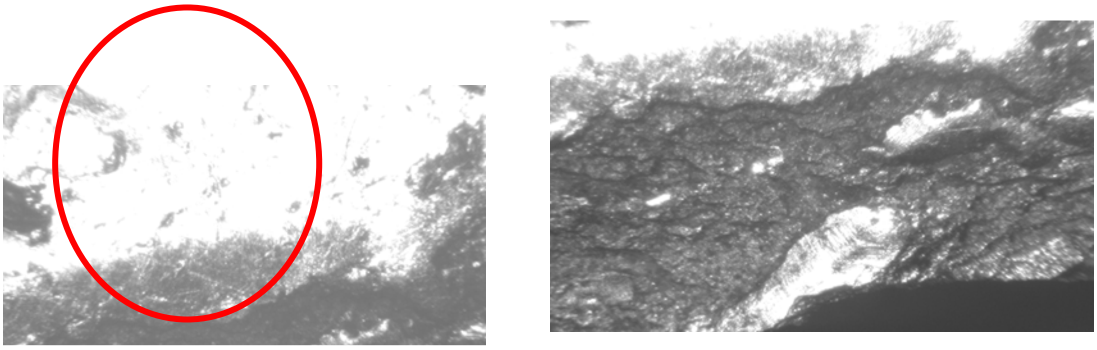


Fig. 8 Detail of fracture area (analysed by KTI –University of Zilina, 2006)

The circled part shown in Fig. 8 (left hand-side) has been the most subjected to friction, i.e. it has been the longest impaired. This part can be assumed as a possible origin causing fracture of the crank shaft. In Fig. 8 (right hand-side) one can see that friction is not as visible, as shown on the left side. The expertise [6] concludes, that the fracture has been initiated in those areas denoted by a red circle as shown in Fig. 8. Testing samples have been taken for further detailed expertise stating the cause of fracture.



a) detail of impairment b) localisaiton of small impairment of material

Fig. 9 Detail of fracture area (analysed by KTI –University of Zilina, 2006)

Fig. 9 represents a detailed view on individual small impairments of basic material's integrity (shiny areas). We can assume that these small cracks have been initiated by thermal processing of basic material and continued to perform and grow (develop) towards the core during operation of the crank shaft, which have weakened the operational cross-section of the material and lowered strength of the crank shaft. We do not assume development of cracks during machining (grinding) from point of view of mechanical properties of material 15 142.

Small surface cracks, up to 0.2÷2mm deep, can develop in different directions, which are not effected by fractures. They are developed as a consequence of tension stresses in a thin surface layer consisting of microstructure of a high hardness and low toughness, which has lower specific volume compared to the microstructure laying under neath. Such difference in specific volume can be caused by decarburized surface, rapid heating, chemical-thermal processing, etc. Development of cracks could be caused by overheating to quenching temperature, rapid heating to quenching temperature, as well as by rapid cooling from quenching temperature, or chemical-thermal processing.

5.2. Theoretical analysis

From experience with the two previously mentioned break-downs of crank shafts of the BL briquetting presses, before any metallographic analysis can be performed, we have decided to undertake constructional changes and strength calculations of the crank shaft once again, in order to discover possible error in original calculations. Constructional changes concerned enlargement of width of crankshaft web, removal of necking and adjustments of roundness of passage radii. Strength analysis was done at the Department of strength of materials of the Faculty of mechanical engineering of the Slovak university of technology in Bratislava. The results obtained were satisfactory. Obtained degree of safety in the critical fracture cross-section was 4.3. Although, the calculations have not been performed during ideal conditions which did not take into account influences accompanied with the failure of material, inappropriate production technology, overloading during operation. During the third break-down where the crankshaft was broken in the identical cross-section, we observed the fracture cross-section at the crankshaft web by help of finite element method performed in the Cosmos Works software. We focused on the influence of increasing width of the crankshaft web (Fig.10) versus safety coefficient in the critical fracture cross-section. Our intention was to repeatedly confirm whether designed crankshaft is not too weak.

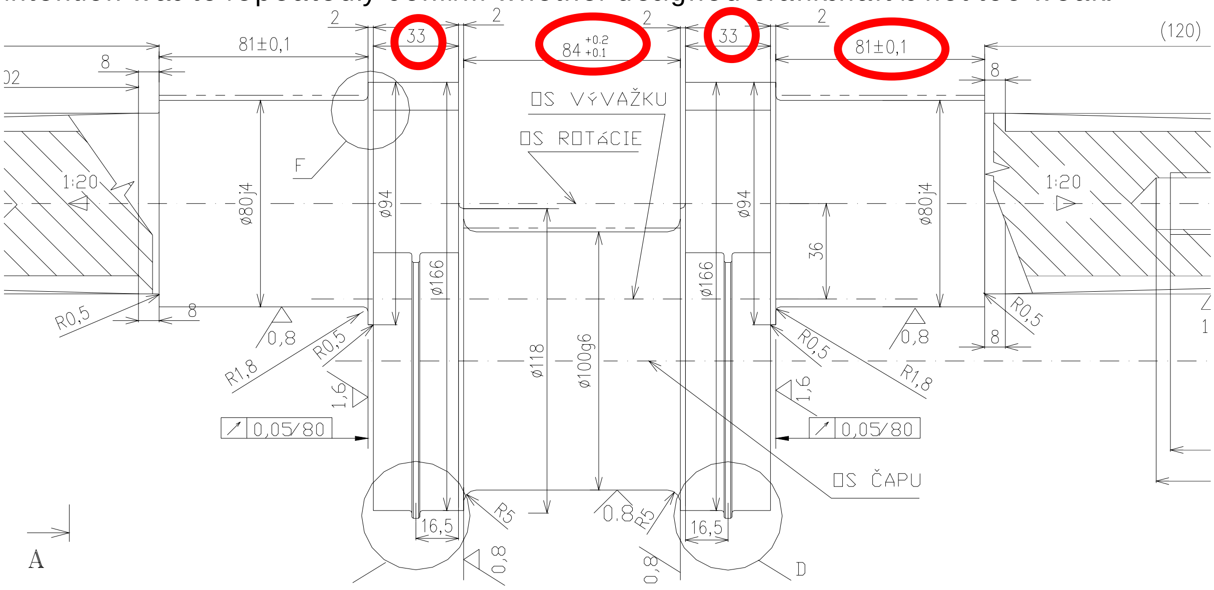


Fig. 10. Detail

Figures 11 and 12 show composition of the safety coefficient on the surface and along the curing plane of the shaft. Finite element method analysis has been divided into two tasks, which of the first one analysis's the shaft during torsion and the second one during bending.

Example of finite element method analysis results during torsion

Max. reduced stress (von Mises): $\tau_{red.}$ = 641 MPa

Safety coefficient versus yield point: k = 1,301

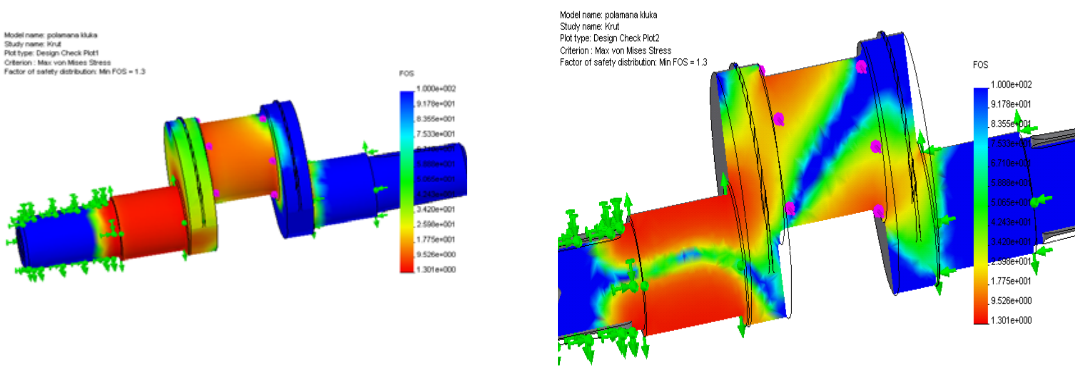


Fig. 11 Security coefficient on the surface and along the cutting plane

Example of finite element method analysis results during bending – crank in the front position
Max. reduced stress (von Mises): $\sigma_{red.}$ = 221 MPa
Safety coefficient versus yield point: k = 3,771

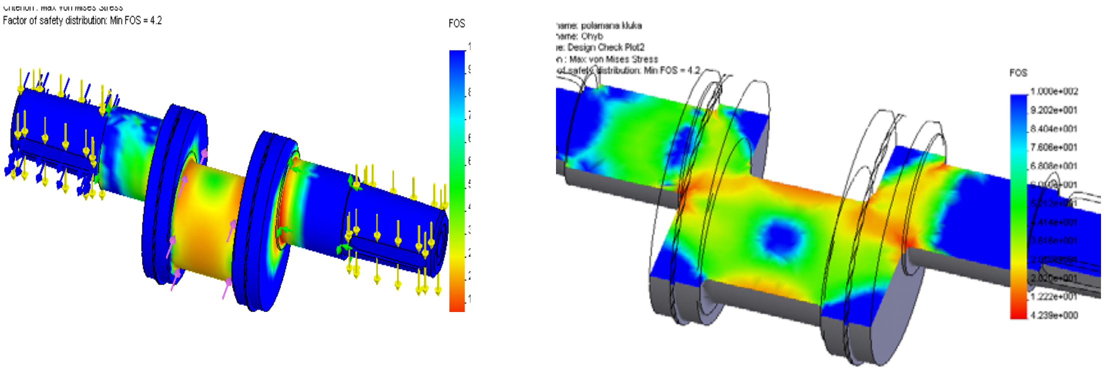


Fig. 12. Safety coefficient on the surface and along the cutting plane

Table 1 shows the relation between the change of crankshaft web versus safety coefficient during torsion and bending. By help of finite element method we observed for example the relation between change of safety coefficient and change of roundness radii of transitions on the shaft, etc.

Tab. 1. Example of comparisement of results of finite element method analysis of the crankshaft

	A		B		C		D	
	torsion	bending crank in the frontal position	torsion	bending crank in the frontal position	torsion	bending crank in the frontal position	torsion	bending crank in the frontal position
Max. stress [MPa] $\sigma_{red.}$ $\tau_{red.}$	641	221	645	198	605	204	638	193
Security Coefficient $k=R_e/\sigma_{red.}$ resp. $R_e/\tau_{red.}$	1,301	3,771	1,294	4,215	1,379	4,084	1,308	4,308
	bending - crank at 90° from the frontal position		bending - crank at 90° from the frontal position		bending - crank at 90° from the frontal position		bending - crank at 90° from the frontal position	
Max. stress [MPa] $\sigma_{red.}$	516		503		508		508	
Security Coefficient $k=R_e/\sigma_{red.}$	1,618		1,657		1,643		1,654	

A Broken crank (original) width of web 33 mm
B Modified crank – webs fortified by 4 mm outwards
C Modified crank – webs fortified by 2 mm inwards
D Modified crank – webs fortified by 4 mm outwards and at the same time by 2 mm inwards

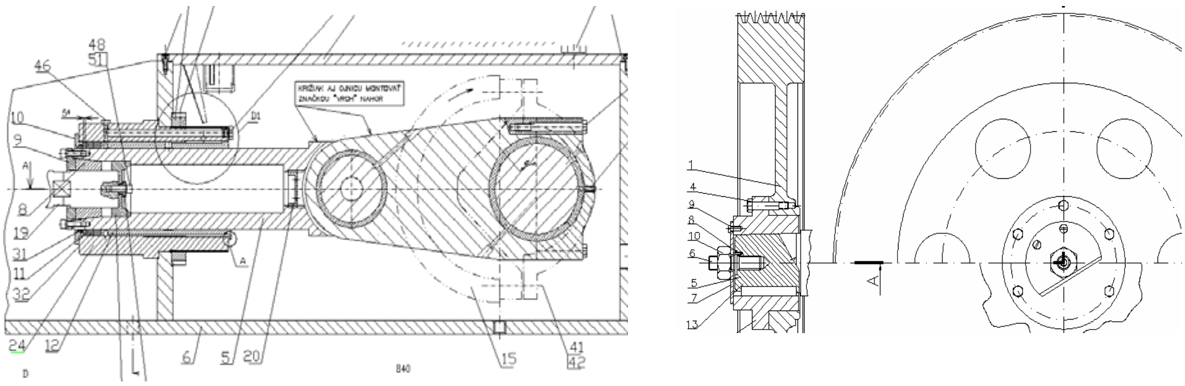
6. CONCLUSION

According to the above stated factors, we would like to concentrate our attention to the design, production, as well as operation of crankshafts.

- determine suitable material for production of crankshaft,

- design suitable transition between individual diameters of the shaft,
- dedicate maximal focus to all transitions between cylindrical and frontal surfaces in order to eliminate potential microscopic sharp transitions which have been left over by the side of the grinding disk (Fig.4). These are points of potential creation of fatigue fracture.
- use appropriate technology of thermal processing
    - o appropriate intensity of cooling during quenching of material,
    - o appropriate velocity of heating to the hardening temperature,
    - o appropriate parameters of surface hardening of the part,
    - o correctly temper the material after hardening,
    - o protect delayed tempering of material after hardening.
- exhaustive fulfillment of prescribed service conditions stated by the producer,
- protect the crank mechanism against overloading by a back-up mechanism – for example suitably placed cutting safety pin (under the piston, on the balancing wheel, ...)

Figure 13 shows examples of cutting safety pin as passive security of the crankshaft mechanism of briquetting press against overloading.



a) cutting security mechanism under the piston b) cutting security mechanism under the balancing wheel

Fig. 13 Security members on the structure BL 55-250

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