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INVESTIGATION OF REASONS AND POSSIBILITY OF PARAMETERS ELIMINATION INFLUENCING CRACKING OF LEAF SPRINGS ON CONTINUOUS CASTING MACHINE

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At the first look very simple and for several hundred years used elastic element can be critical part in complex equipment where its failure invokes extraordinary high losses. In the paper is given a treatment for the solution of this problem by experimental methods and resulting proposal for its final solution.

Key words: *crystallizer, leaf springs, mechanical properties, fatigue tests, microstructure of materials*

Istraživanje razloga i mogućnosti eliminacije parametara koji utječu na pucanje lisnatih opruga na stroju za kontinuirano lijevanje. Na prvi pogled vrlo jednostavan i nekoliko stotina godina korišten elastični element može biti kritičan dio u složenom okruženju gdje njegov kvar izaziva iznimno velike gubitke. Ovaj članak daje postupak za rješenje tog problema eksperimentalnim metodama i rezultirajući prijedlog za njegovo konačno rješenje.

Ključne riječi: *kristalizator, lisnate opruge, mehanička svojstva, testovi zamora materijala, mikrostruktura materijala*

INTRODUCTION

During production of slabs by continuous casting the steel is distributed through number of gits in vertical direction into copper form cooled by water. Heat is conducted through the copper into the water and during this process solidification of surface layer of liquid steel occurs. In order to prevent sticking of solidified layer to the copper plates, it is necessary to vibrate crystallizer and this is for various velocities of casting controlled by computer. Crystallizer is positioned in vibration mechanism that ensures vibration movement.

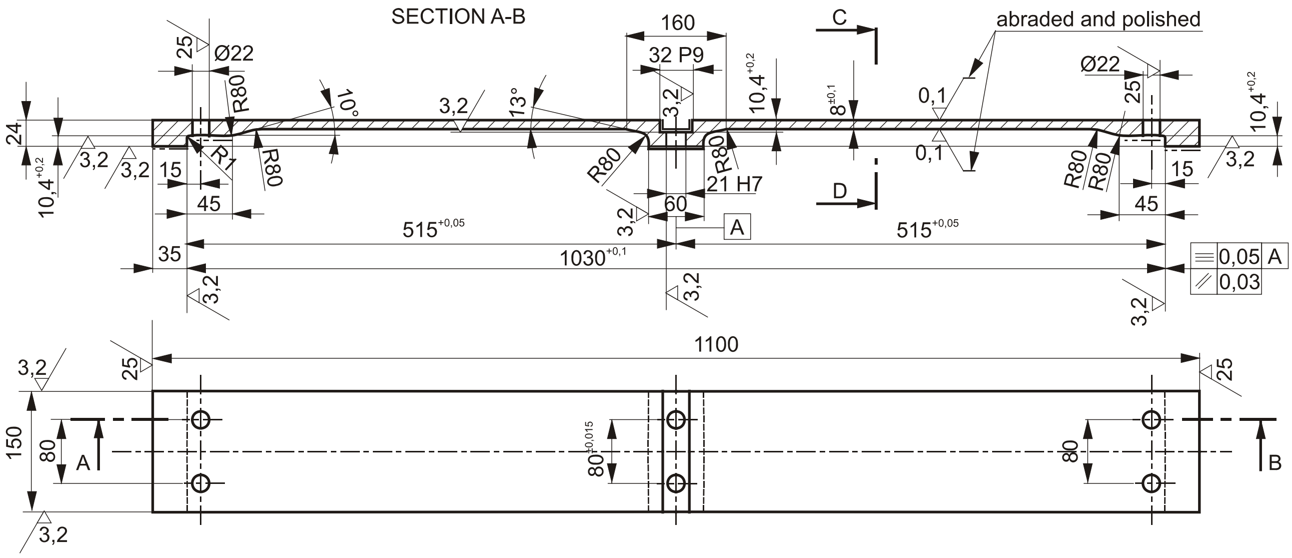

Figure 1. **Shape and dimensions of leaf spring**
Slika 1. **Oblik i dimenzije lisnate opruge**

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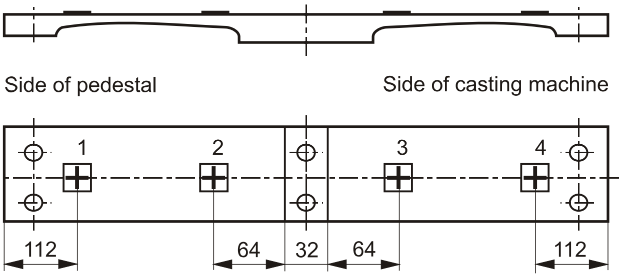
The vibration mechanism is equipped by two leaf springs (Figure 1.) that transfer forces between moving and stationary parts of vibration mechanism. During operation premature failures of leaf springs occur. The number of spring damages is different on two continuous casting machines that are in operation. Slope angle of leaf springs to the horizontal plane is 4,574° and 5,71°, respectively and the maximal vertical deflection (2,95 mm in the middle of spring - location S) is ensured by eccentric shafts.

During solution of this problem the residual stresses in broken leaf spring were determined by the hole drilling method. Strain gages for the hole drilling method can be seen in Figure 2. The maximal level of residual stresses (pressure) does not exceed 40 MPa.

Figure 2. **Locations of strain gages RY 61 for the hole drilling method**
Slika 2. **Lokacije tenzometra RY 61 za metodu bušenja rupe**



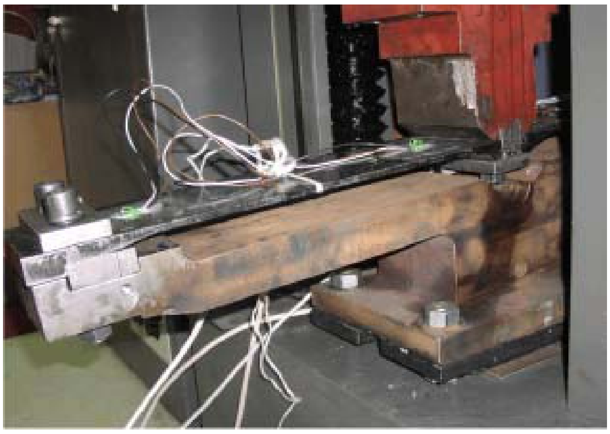


Figure 3. **Leaf spring with applied strain gages in tensile machine**
Slika 3. **Lisnata opruga s primijenjenim tenzometrom u stroju za mjerenje otpora na istezanje**

Strain gage measurements of stresses in leaf spring were realized for fastened spring ends and prescribed vertical deformation of leaf spring in tensile machine. In order to provide the measurements on leaf springs in the tensile test machine it was necessary to use holding fixture because leaf spring is not in horizontal position and axial component of force should cause shifting of spring from pedestal of tensile machine. Fastening of holding fixture together with leaf spring is given in Figure 4.

Methodology of the measurement was, with respect to the needs of using different heads and gages for the measurement with pressure and tension, developed only for the tests with pressure force. The authors has supposed that type of binding between spring and holding fixture as well as prestress in the spring has big influence on relation between deformation and the force needed for creation of prescribed deflection and so were these assumptions experimentally tested.

Leaf spring was freely placed on holding fixture and the chucking wedges were completely free. The bolts on the ends of leaf spring were completely free too. After movement of traverse of the tensile machine to the neighborhood of leaf spring and after equilibrating of strain gage apparatus the measurement began. The records in figures from individual measurements represent stress levels in axial direction of leaf spring in locations 1 to 4 (Figure 4.). The steps correspond to the change of deflection by 0,5 mm. The measurement was provided during loading as well as unloading.

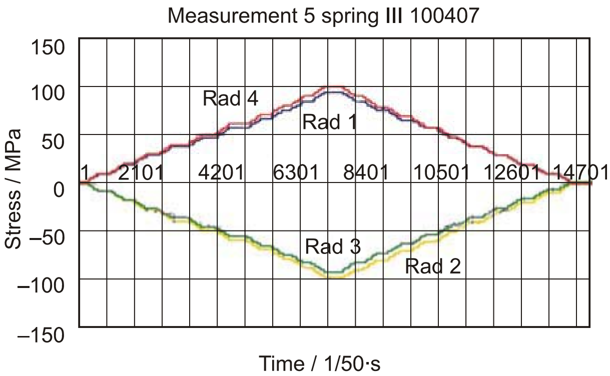


Figure 4. **Time-dependent chart of stresses in locations 1, 2, 3, 4**
Slika 4. **Vremenski ovisni dijagram naprezanja na lokacijama 1, 2, 3, 4**

The stress measurement of springs in the frame of equipment for continuous casting of slabs was realized after calibration in

Figure 5. **Leaf spring positioned in frame**
Slika 5. **Lisnata opruga pozicionirana u okviru**

tensile machine and after positioning of springs into the frame (sees Figure 5.).

The measurement was realized on testing stand. For the appraisal of spring behavior during the operation were the measurements realized on testing frame of crystallizer during its vibration. Two leaf springs with strain gages were built into vibration mechanism. After zeroing of individual strain gages there was found that maximal stress levels registered by all biaxial strain gages during frame vibration are approximately at the same levels and the differences are only in signs of stresses. In Figure 6. is given time-dependent chart of stresses in spring during vibration of crystallizer.

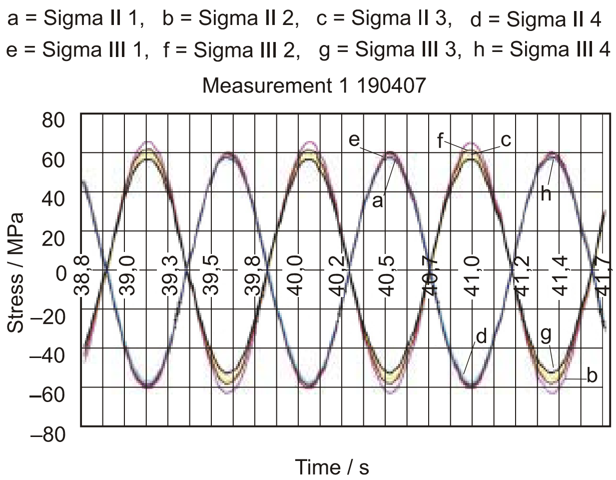


Figure 6. **Time-dependent chart of stresses in spring during frame vibration**
Slika 6. **Vremenski ovisni dijagram naprezanja opruge za vrijeme vibracije okvira**

At the same time were measured horizontal and vertical displacements of crystallizer frame as well as accelerations of points in vertical direction in the center of the springs. The measurements did not show any phenomenon during vibration of crystallizer in testing frame that could result to the failures. The measurements were realized for various casting velocities, various slabs widths, for small and big changes of their dimensions and various materials. Detailed analysis was also performed by the finite element method. The computations were accomplished for prescribed displacements of the center of leaf spring in axial direction to the value of 0,2 mm and in vertical direction by 2,95 mm. Analyses have confirmed that the spring from the point of view of fatigue loading conforms to all conditions.

From the analysis of results gained from analytical, numerical and experimental methods was found out that leaf springs in vibration mechanism are from the point of view of save operation under common working regimes made of suitable material and their dimensions and fastening should in full range ensure correct operation of continuous casting machine. Failures - damages of these springs document that the states during which these phenomena arise are not common working states and it is not necessary to change the geometry and material of springs or their fastening. It is necessary to remove phenomena that cause overloading and to this time were not satisfactorily revealed.

MECHANICAL PROPERTIES AND METALLOGRAPHY

Testing samples (bar 6 × 30) were made from the given material of leaf spring made of Cr-Ni-Mo martensitic stainless steel 1,4418 in accordance with STN EN ISO 377 and OEG 13 1011. Testing bars were taken from the area of transition part (from the thicker part on boundary to the constant thickness, marked 1) as well as from flat part of leaf spring, marked 2.

Tensile test was realized on tensile machine FP 100/1 under temperature +20 °C according to STN EN 10002-1+AC1, júl 1997. The results of measurements are given in Table 1.

Table 1. **Mechanical properties of tested material - measured and prescribed**
Tablica 1. **Mehanička svojstva testiranog materijala - izmjerena i propisana**

Specimen	$R_{p0,2}$ / MPa	R_m / MPa	A_5 / MPa	Z / %
1	843	991	22,7	63,1
2	836	995	21,7	62,1
Prescribed	700	900 - 1100	14,0	-

In Figure 7. is documented the microstructure from the area of geometrical transition of leaf spring (change of spring thickness). Microstructure in Figure 7. is acicular and it corresponds to low carbonaceous martensit.

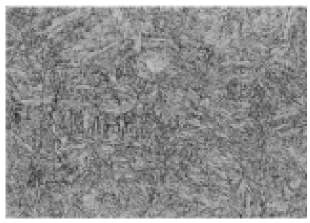


Figure 7. **Microstructure of tested material**
Slika 7. **Mikrostruktura testiranog materijala**

On the base of accomplished experiments can be stated that:

- mechanical properties of tested leaf spring are in accordance with Cr-Ni-Mo martensitic stainless steel upgraded to quality QT900,
- microstructure corresponds to low carbonaceous annealed martensit.

Microstructure is composed from coarse annealed needles of martensit with visible boundaries of coarse grain that can have influence to the strength of material.

During the analysis of results the authors have given their attention to possibilities of increasing of working life of leaf springs by improving of mechanical properties by more suitable technology of heat treatment. This orientation was caused by fact that microstructure of material contains coarse annealed needles of martensit. Unfortunately, it was discovered that these changes do not remove the problems. It was the reason for using another material for which can be reached yield point 1700 - 1900 MPa and strength limit 1800 - 2050 MPa by appropriate processing. The material for such elements can by the steels of maraging type. The steels belong to this group not by their chemical composition but by the strengthen mechanism that is based on precipitation of intermetallic phases in matrices (aging) almost non-carbonaceous martensit. Maraging steels are produced approximately for 25 years. At the beginning they were low carbonaceous (to 0,03 % C) steels in which the main element was nickel in amount 8 - 25 %. They contained mainly 20 - 25 % Ni with additions of Ti, Al and Nb. Next stage were alloys from the system Fe-Ni-Co-Mo with addition of Ti. The most spread steels of this type contain 18 % Ni. American specification expresses (besides of Ni) yield point in units ksi (1 ksi = 7 MPa), russian specification characterizes chemical

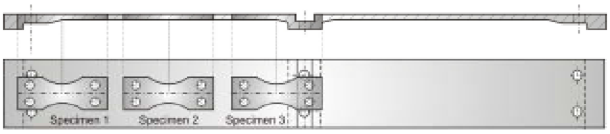


Figure 8. **Scheme of locations from which the specimens for fatigue tests of leaf spring were taken**
Slika 8. **Shema lokacija s kojih su uzeti uzorci za testove zamora materijala lisnate opruge**

composition. Specific steels are known also according to various corporate names e.g. steel 18Ni250 grade under names: Vascomax 250, Nimar 110, Almar 18-250, Marvac 250, Republic RSM-250, Murphy 1.

FATIGUE TESTS ON SPECIMENS TAKEN FROM THE DAMAGED LEAF SPRING

The fatigue tests were based on using of testing machine PWY from SCHENCK corporation. Because leaf spring is loaded for correct setting by symmetrical bending, this type loading was chosen also for this machine. The specimens were made according to Figure 8.

Figure 9. **Specimen 1 for fatigue test taken from the boundary of spring**
Slika 9. **Uzorak 1 za test zamora materijala uzet s ruba opruge**

On the flat surfaces of specimens 1 to 3 were applied in the most narrow cross sections the strain gages 1-XY91-10/120 with gage factor k = 2,05 and resistance 120 Ω. The grid of the strain gage perpendicular to the axis of the specimen is used for thermal compensation and at the same time in the sense of Hooke's law it comprises also influence of transversal deformation. Specimens 2 and 3 were chosen such a way that they have stress concentrator in the most narrow part of the specimen's cross section. In Figures 9. to 12. are shown specimens 1 to 3 taken from positions of leaf spring according to Figure 8.

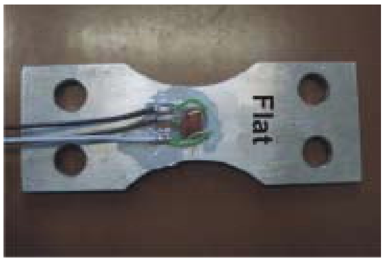


Figure 10. **Specimen 2 for fatigue test taken the from the flat part of spring**
Slika 10. **Uzorak 2 za test zamora materijala uzet iz plosnatog dijela opruge**

Figure 11. **Specimen 1 for fatigue test taken the from the middle part of spring**
Slika 11. **Uzorak 1 za test zamora materijala uzet iz srednjeg dijela opruge**

Fastening of test specimen in clamping jaw of the testing machine PWY is shown in Figure 12. Fatigue tests of leaf spring were based on the thesis that fatigue limit of leaf spring material is according to State research institute of materials in Prague for symmetrical bending σ_{co} = 0,43 R_m.

According to the producer, the mechanical properties of material of leaf springs are: strength limit R_m = 1050 MPa and so σ_{co} = 0,43·1050 = 452 MPa.

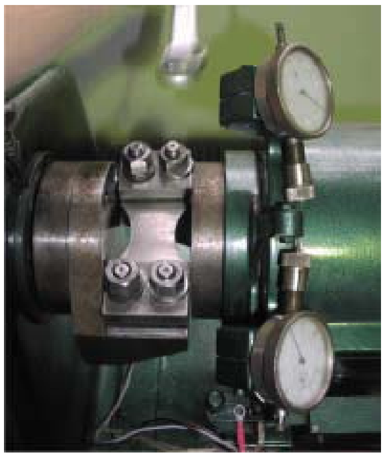


Figure 12. **Fixation of test specimen in test machine PWY**
Slika 12. **Fiksacija testnog uzorka na testnom stroju PWY**

Fatigue limit mentioned above is given for the specimen with polished surface. That is the reason why boundary specimen was after its fixation in testing machine (Figure 12.) loaded by symmetrical bending with amplitude of stress that corresponds to the fatigue limit for symmetrical bending. After 2,6786·10^6 cycles was clearly demonstrated that fatigue limit of this material exceeds this value. Further were increased the stress amplitudes and after certain number of cycles for the defined amplitudes was the specimen damaged.

In Figures 13. to 15. photographs of fractured specimens 1 to 3 is given. From the structure of the fracture surface is seen that it contains segregates inclusions visible without microscope. These were probably introduced into the material by incorrect technology of leaf spring production. Inhomogeneous structure of material is located in several points of the cross section (see Figure 13.).

Figure 13. **Fracture surface of boundary specimen 1**
Slika 13. **Površina pukotine rubnog uzorka 1**

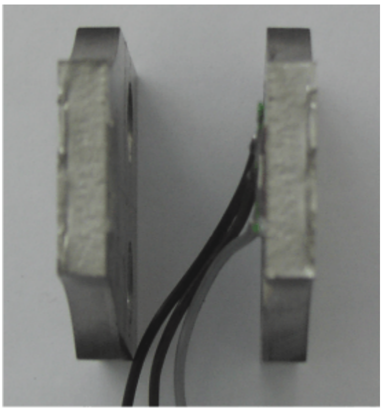


Figure 14. **Fracture surface of specimen 2**
Slika 14. **Površina pukotine uzorka 2**

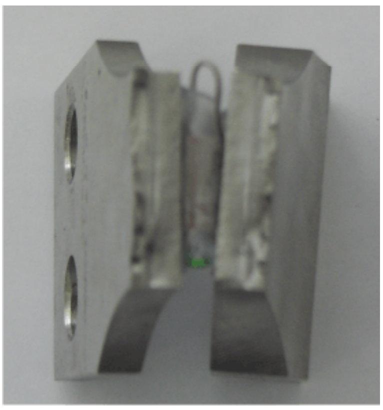


Figure 15. **Fracture surface of middle specimen 3**
Slika 15. **Površina pukotine srednjeg uzorka 3**

In the Figure 14. is shown fracture surface of the specimen 2 that was taken from the middle part of spring. This part is without any segregates inclusions or visible defects.

In Figure 15. is fracture surface of the specimen 3 in the area of transition from thin to thicker middle part of spring. In this part of cross section are again visible conspicuous inclusions in the fracture surface.

CONCLUSIONS

The analysis of results gained from analytical, numerical and experimental methods demonstrates that leaf springs in the vibration mechanism are from the point of view of safe operation under common working regimes made of appropriate material and their dimensions and fastening should in full range fulfill all requirements needed for proper operation of continuous casting machine.

Failures - fractures of these springs document that the states under which arise these phenomena are not common operation states and accordingly it is not necessary to change material of springs, their dimensions or fastening. However, it is necessary to remove the phenomena that invoke extreme overloading, especially at the beginning of operation.

For the solution of problem of spring breaking, at least to the time of determination of extraordinary load combination, we suggest to use material with markedly higher strength properties.

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