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BARTELL ROTARY BASKETS

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Abstract: *The aim of this paper is to solve the problem with emerging and growing fatigue cracks in Bartell rotary baskets operated in NKT cables s.r.o. Carried out were several strength analyses, strain-gauge stress measurements, mechanical vibration measurements on the mounting frame of the basket rotor bearings, magnetic particle tests, modal and harmonic analyses. The benefits of design modifications were assessed. Suitability of the technology used. Teams of people across the Republic dealt with the device. The original baskets were manufactured by the Canadian-American company Bartell. The cracks appeared after 3 months of operation and gradually expanded to such an extent that the device was unable to operate. Subsequently, new baskets were manufactured according to the design of Pemavako s.r.o., that slightly improved the original baskets. Cracks were detected on these improved baskets after 8 months of operation, the device is still in use and the user wishes to extend its life as much as possible.*

Keywords: Fatigue cracks, Strength and elasticity analysis, Rotary device, Strain-gauge measurements, Change of structure by welding.

1. Introduction - Device description

These are two steel weldments designed to carry the spools with copper wire, which is unwound by rotation. Passing through the dies, it is wrapped around the core of the cable that passes through the centre of the basket. The baskets are in tandem on the machine. Up to 4 copper wire spools can be placed in each basket box. Each basket has 7 boxes. The spool with the maximum wire load weighs 650 kg. The baskets are put in motion by a belt drive from one side of the basket (Fig. 1).

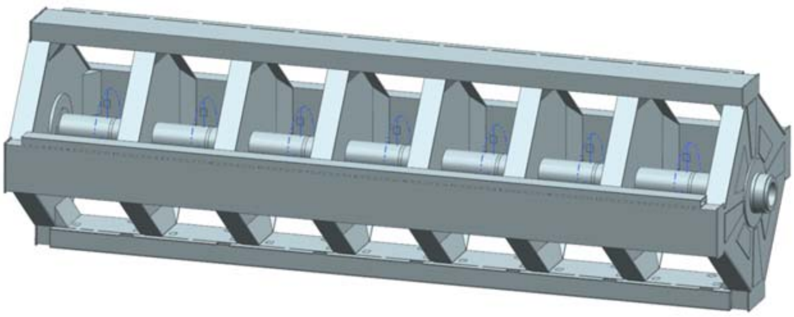

Fig. 1: Assembly of one rotary basket.

2. Boundary conditions

Boundary conditions of the rotary basket (Fig. 2) are the following:

- full spool rotation at 110 rpm and emergency braking in 4 sec.,
- maximum weight of the spool is 650 kg (including wire filling), the total number of spools on one basket is max. 28,
- weight of one unwinder is 60 kg, total number of unwinders on one basket is 28 pcs,
- effect of gravity,
- effect of rotation of 110 rpm,

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- effect of brake deceleration of 165 deg/s^2,
- basket material: S690Q,
- alternating load of 34 700 000 cycles per 1 year - high cycle fatigue.

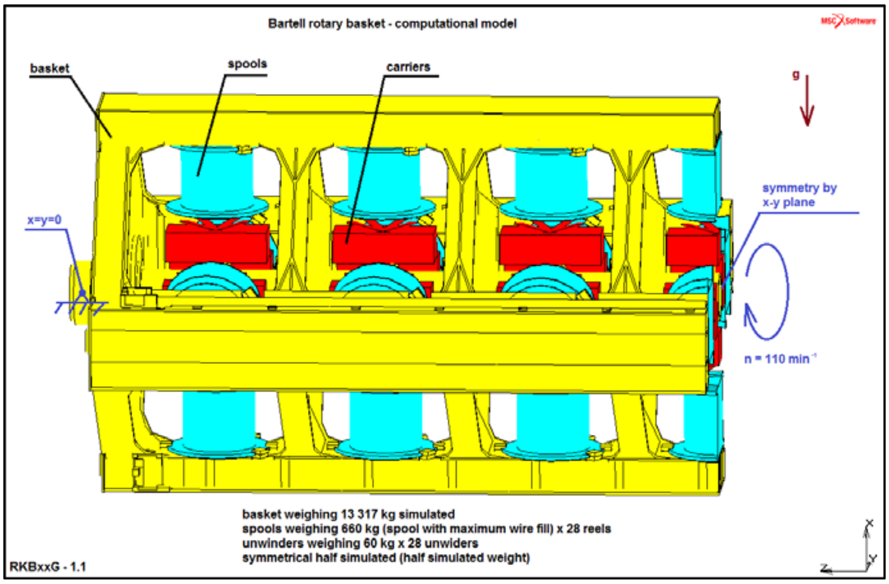

Fig. 2: Computational model for elasticity and strength analysis by ŽĎAS, a. s.

3. Results of computational analyses

3.1. Analysis by PEMAVAKO company

It compares its design with the original one by Bartell for input parameters of 110 or 200 rpm. Both for normal operation and so-called STOP STATUS, when the device is braked.

Tab. 1: Stress dependence on boundary conditions.

	Max. stress [MPa]		Max. detailed stress [MPa]	
Load state	Original	New	Original	New
110	294	72	215	59
110+STOP	320	67	244	62
200	393	176	365	136
200+STOP	416	172	238	95

Tab. 1 shows a multiple reduction of the stress according to FEM (Kosnar, 2015 and 2016). For example, changing the material from the original 12050 to the S690Q means roughly twice the yield strength. These were the reasons why NKT Cables believed that the fatigue cracks would no longer form in the device acc. to PEMAVAKO design. After 8 months of operation, 19 cracks were found. PEMAVAKO made its second analysis. The cause of the cracks was determined as follows: "Examination of the welded basket construction revealed that during the production technology there was a deviation from the assumed design, which was included in the computational models. This contradiction caused a notch in the affected areas with cracks and also weakened the transmission area by at least half. The result is a high stress concentration (over 250 MPa) in the notches. The amount of stress in these areas exceeds the fatigue limits of the welds for the current number of cycles (180 MPa), thereby causing fatigue failure of the material. Over 10 million revolutions have been cycled until the crack detection, which is taken as the lower service life limit of the Wőhler curve for steel".

They suggested a repair: "The first part of the repair (grinding and continuous welding of the cracks) evokes a condition in the structure that was originally considered in the computational analyses. The stress results of these analyses (in notches around 130 MPa - element size 1mm - sharp transition is considered!) were below the fatigue limit of the material. The second part of the repair (welding of the repair ribs) takes a part of the stresses from the currently cracked areas, thus increasing the safety for repeated cracking in the fatigue-affected areas. The maximum stress in the repaired areas reaches values up to 60 MPa". Despite their repairs, the problem of emerging and spreading fatigue cracks continues.

3.2. Analysis by the University of West Bohemia in Pilsen, Faculty of Mechanical Engineering, Department of Machine Design

In particular, it is important to note that the braking speed is almost irrelevant (Čechura et al., 2016). On the other hand, the operating speed has a significant influence on the fatigue life.

All calculations were performed assuming that all joints and materials used were homogeneous. From the results of the calculations it is clear that the increase of the drum speed from 110 to 200 rpm is significantly reflected in the magnitude of the stress in the individual parts of the drum; increased stresses also appear in once less exposed areas. Considering the load only from the effect of increasing the rotation to 200 rpm, there is a stress in the rib A up and down exceeding 100 MPa, which is a considerable increase compared to the original condition at 110 rpm./ min. Of course, this was also reflected in the results of the calculations of the complex load of the basket (by all the mentioned external effects), when the rib stress at the point A up dropped from 91 MPa to 86 MPa, but on the contrary the rib stress at the point A down dangerously increased from 87 MPa to 176 MPa in a small stress field. As can be seen from the figures, there is also a much greater displacement of the exposed parts of the basket compared to the original condition.

3.3. Analysis by AK-Mechanika, s.r.o.

The basis for this analysis was, in addition to the input data, also the measurement of mechanical vibrations on the mounting frame of basket rotor bearings. Input parameters for numerical analysis were adjusted based on the measurements. The results have already been such that the existing device does not meet the requirements of high cycle fatigue (Paščenko et al., 2017). The conclusion of this analysis states, inter alia, as follows:

"The results of the computational analysis show that the reinforced rotary basket weldment is satisfactory in terms of strength, but is UNSATISFACTORY in terms of high cycle fatigue. In a relatively short time, months of operation, the formation and spread of fatigue cracks can be expected in narrowly local areas of welded joints of the side walls. Appropriate structural modifications should therefore be made without delay to increase the resistance of the rotary basket to high cycle fatigue sufficiently."

3.4. Analysis by ŽĎAS, a. s.

In February 2018, the main point of the computation conclusion was: "For the specified maximum service load, the above material and range of working temperatures of Bartell rotary basket weldment meet, in terms of normally required safety, the limiting state of fatigue with safety of at least 1.278 per 107 duty cycles of load (limit for permanent life). After adjusting the input conditions on the basis of the measurements, the device did not already meet the permanent life requirements according to the strength analysis according to ŽĎAS standards. Design changes have been proposed to extend its service life (Gregor, 2018). For such modified basket faces, the highest stress in the baskets drops by 18 % (Fig. 3).

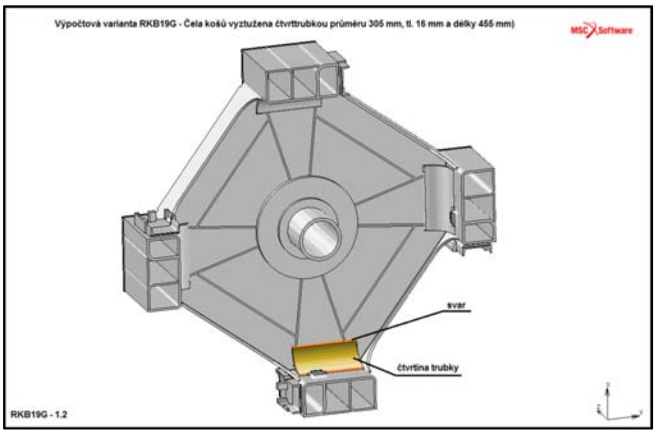

Fig. 3: Design modification proposed by ŽĎAS, a. s.

4. Strain-gauge measurements

ÚAM Brno, s. r. o. performed the strain-gauge measurements on the BARTEL-CEECO winding basket: “From the measurements it can be seen that the values of oscillations of the reduced stress determined by FEM analysis are similar to those measured by the strain-gauge rosettes. On this assumption, it is also possible to agree to the maximum values of reduced stresses achieved by FEM calculations.” The measurement report (Valenta, 2014) also states: “The material (base body, original weld metal) and its fatigue and / or fracture properties are unknown. Insufficient thermal cycle during the welding (brittle structures) can also be dangerous in terms of material fatigue.” At the end of the protocol, there is a technical opinion on the test: “Based on the measured and observed values, it can be stated: Based on the visual inspection it can be stated that the crack propagation continues despite the reinforcement of exposed areas according to the manufacturer's recommendations. On the basis of the strain-gauge measurements, it can be stated that the mechanical stress at the specified locations is within the expected range according to the FEM model.”

Furthermore, one of the authors of the strain-gauge measurements considers that in the places of welding the structure changes to martensitic one, which leads to subsequent fatigue cracks. These martensitic structures cannot be eliminated by vibrations. He recommends to anneal the entire basket. Alternatively, to select at least one of the local annealing methods. For example, to add 2 to 3 welding passes and then to grind them with angle grinder to use blankets for preheating.

5. Conclusion

At this moment the latest magnetic particle test report shows 21 detected cracks up to 500 mm in length. The device is operated at reduced speed (about 70 rpm). It is planned to repair the cracks by grinding and welding and to change the design according to Fig. 4. Subsequently, the cracks formation and growing and problem repetition are expected. Stress relief annealing, which could help significantly, is not planned. There remain a number of uncertainties about the materials that have ever been welded on there.

And what is most important. For the initiation of fatigue damage, the stresses in the structural notches are predominant. The new design could be realized with smoother transitions of individual basket elements. Also in the new construction, it would be advisable to create unloading windows and aim for the lowest possible weight. Then there would be less stress from the centrifugal forces, with the rotation of less mass. Not to mention the smaller oscillation at the alternating bending during rotation, which takes place here with each revolution. However, the current structure can only be supplemented with some elements and the forming cracks repaired in order to extent the service life of the device by some time.

Fig. 4: One of the detected cracks

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