Innovative solution for repairing and increasing the operational safety of rotary drum mill spindles

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Abstract. The paper presents a welding repair technology for bottom of the mill as well as a constructive solution for increasing the safety in their operation. The article is structured on two main directions, a technological one - the spindle repair and the other with finite elements for increasing the safety in operation. In the first part are presented the problems related to the occurrence of defects during the operation of rotary. Most defects are: geometrical deformations, cracks, metal cracks, followed by damage. It is presented how to repair by welding the mill by removing the metal cracked area and mounting a compensating ring. To minimize deformations, a on centering device, for flange + ring + cylinder was designed and built. In the second part, using finite element programs, are presented the result of the mechanical stresses of the used spindle and a new constructive variant that ensures an increased safety in operation. With the help of the finite element analysis software, the geometric shape and the degree of stress was optimized. From the calculations a decrease of up to 50% of the geometrical deformations occurred and a decrease of up to 70% of the stresses in the requested area.

1. Introduction

The paper presents a welding repair technology for bottom of the mill as well as a constructive solution for increasing the safety in their operation. In the first part of the paper, we present the defects that occur during the operation of rotary drum mill spindles: cracks, metal breaks etc. and the welding repair technology. In the second part of the paper, we present a new reinforcing solution for increasing the operational safety of the spindles. The new solution was chosen after the finite elements analysis of some possible constructive variants using the ANSYS software. After changing the geometric shape, it was found that the values of the strains decreased by 70% and their maximum values are found in another area, namely in the reinforcement area, thus increasing the safety of operation and the life of the product.

Rotary drum mills are currently being built in a wide variety of constructions. In principle, such a mill consists of a cylindrical horizontal drum at the ends of which are the spindles that have the role of both cap and support - bearing. The geometric axis is also the axis of rotation. The flow of such a mill is between 10 - 300 tons/hour. The mill that is the subject of this study has a flow rate of 120 tons per hour and grinds bauxite, its basic diagram being presented in figure 1.

Drum 1, with the dimensions D×L (3.5 × 14.2 m), is supported between the bearings #2 and #2’ and is driven in rotation by a drive device formed by an electric motor and a reducer. The drum is partially filled with the grinding load formed from free grinding bodies and the grinding material, the filling rate being between 30-45% of the drum capacity. Due to the rotation of the drum, at a certain speed of 14-18 revolutions per minute, the grinding bodies are driven in motion and raised to a height H<D, from
where they fall freely. The crushing of the material occurs as a result of the combined impact and shearing effect of the falling grinding bodies. These mills run continuously.

Figure 1. Diagram of a rotary drum mill: 1- drum; 2, 2'-bearings; 3- mill spindle.

The greatest mechanical stresses are in the two spindles and especially in the area of transition from the taper to the cylindrical shape (figure 2). The spindles are made of GE240 SR EN 10293:2005 cast steel [1]. Technical specifications:
- Overall dimensions: L = 14.2 m, D = 3.5 m;
- Distance between the bearings = 16.5 m;
- Assembly weight = 250 tons;
- Weight of grinding body = 120 tons;
- Weight of the ore = 46 tons;
- Nominal work speed = 18 rpm.

Figure 2. Mill spindle: cross section.

During operation, the spindle is subjected to various stresses, namely: torsion, shear, shock, fatigue [2]. The dimensions of the spindles are according to the standards in force. The main components of the mill are calculated according to the geometric dimensions and then the exact dimensioning is made according to the stresses to which the spindle is subjected (figure 3), namely:
1. \( R \) - mean spindle tube radius
   \[ R = 0.22D = 0.385 \text{ m} \]
2. \( S_1 \) - thickness of the taper head in the area of connection with the spindle
   \[ S_1 = (15 + 0.52 \text{ LD}^2) \times 10^{-3} = 0.105 \text{ m} \]
3. \( S_2 \) - thickness of the taper head in the area of connection with the drum mounting flange
   \[ S_2 = 0.01 \times D = 0.035 \text{ m} \]
4. \( S_3 \) - drum wall thickness
   \[ S_3 = (16 + 0.12 \text{ LD}^2) \times 10^{-3} = 0.036 \text{ m} \]
5. \( S_4 \) - drum shield thickness
\[ S_d = 0.018 \ D = 0.063 \ m \]

6. Determining the operating speed of the mill:
   a) The critical speed that cannot be exceeded and where the grinding bodies rotate jointly with the drum without coming off is given by the relationship:
   \[ n_{cr} = \frac{42.3}{\sqrt{D_m}} = 24.81 \approx 25 \text{ rpm} \] (1)
   b) The operating speed of the mill is determined as follows:
   \[ n_r = \frac{k}{\sqrt{D_m}} = 17.64 \approx 18 \text{ rpm} \] (2)

Taking into account the above facts, the following mechanical stresses result in the area of transition from the taper to the cylindrical shape:
1) Torque moment \( M_t = 1061 \text{ kNm} \);
2) Bending moment \( M_{i_1} = 2850 \text{ kNm} \) on the \( X \) axis;
3) Bending moment \( M_{i_2} = 450 \text{ kNm} \) on the \( Y \) axis.

Figure 3. Sizing of spindles.

2. Repair technology
Most often cracks appear in the connection area and propagate approximately circularly leading to a rupture of the spindle in the course of time. The most stressed area is the area of transition from the truncated cone geometrical shape to the cylindrical shape. Below are the images of the broken and reconditioned spindle (figure 4).

In order to recondition the mill spindle, the following steps were taken:
   a) Removal of the cracked area

   Removal of the cracked area consists essentially in the complete detachment of the two geometric shapes, the truncated cone - the clamping flange, and the cylinder body. Typically, these parts were made between 1975 and 1980, already having a very high number of hours of operation. The values of mechanical properties have decreased and being a cast steel with many cracks and material breaks, the removal of the area can be done only by mechanical cutting, namely by drilling, making successive holes. If the cutting is totally thermal, with the oxy-gas flame, there is the risk that certain cracks will spread from the defective area to the rest of the part, making it almost impossible to repair. That’s why it was avoided as long as it was possible to insert the heat into the cutter. The thickness of the material is about 120 mm. For the repaired part, the cracked area started next to the cylinder and expanded over a width of 250 mm on the taper side.
Figure 4. Spindle image: (a) - broken; (b) - reconditioned.

b) Mechanical machining of subassemblies
The two subassemblies were machined by cutting on CNC carousel lathe (figure 5), thus ensuring the following elements:
- removal of the area adjacent to the cracks;
- straightening of the surface and its machining for further welding;
- concentricity of the subassemblies;
- possibility of performing a non-destructive control of the surface to be welded.

Figure 5. Cylinder machining: (a) - external cylindrical turning; (b) - finishing.

Checks were made with penetrating liquids and magnetic powders (figure 6).

Figure 6. Flange machining: (a) - mechanical cutting; (b) - final control.

c) Design and construction of a compensating ring to connect the flange to the cylinder. Following the removal of the cracked area, there was a lack of material in the form of a flange-type ring with a width of 250 mm. It was made of a 120 mm thick sheet and was loaded on both sides by welding so as to achieve the desired flange inclination (figure 7).
After loading, the intermediate ring was machined on the lathe to obtain the shape and dimensions required for welding faggot of the assembly. Due to the shape of the parts, a K-shaped gap resulted.

![Figure 7](image)

**Figure 7.** Diagram of the subassembly: 1 - cylinder; 2 - compensating ring; 3 - flange.

d) **Design and construction of a centring device**

For assembling the 3 parts, the cylinder + compensation ring + flange, a centring device common for all components was designed and constructed. The flange and the compensating ring were assembled first, after which the final assembly of the cylinder was carried out [10]. Thanks to the device designed and constructed by the authors, the deviation from concentricity was within the prescribed limits (being only 0.5 mm, a very good value considering the overall dimensions, 3.5 m).

The centring technique used was the following. In order to materialize the centre of the assembly, a modular device consisting of:

1) **A radial system consisting of 6 arms**.

On a hexagonal plate with 400mm side and 20mm thick, an Ø 50mm centring hole was made. On each side of the hexagon, six rigid arms radially arranged were welded. Taking into account the value of the centring diameter of the flange fastening holes, the 6 arms were properly drilled. In the given holes, the collar bolts were mounted and welded. The bolts enter the flange holes, thus centring the hexagonal plate.

2) **A system for positioning and centring of the compensating ring and spindle cylinder**.

The radial system thus created is mounted in the flange of the spindle and then turned both 180 degrees with the bolts upwards. In the hexagonal plate, a centring plate 4, an intermediate bush 5 and a centring holder 6 (figure 8) are inserted by turns. This holder also takes the weight of the cylinder through its 4 legs 7.

![Figure 8](image)

**Figure 8.** Diagram of the centering device: a - axonometric view; b - cross section; 1 - hexagonal plate; 2 - arm; 3 - bolt; 4 - centring plate; 5 - intermediate bushing; 6 - centring holder; 7 - support leg.

After a pre-assembly, the welding of the flange compensating ring was first done and then the cylinder was mounted and welded to the rest of the subassembly. Figure 9 shows images of the mounting and welding stages.
3. Welding technology

The MAG process was used to faggot by welding the elements due to the following considerations [3]:
- allows for high quality welded joints;
- allows welding in difficult positions and introduces low stress into the joint;
- because of the high concentration of the spring energy, a minimum area of structural transformations and relatively low deformations of the welded parts is preserved;
- the absence of slag provides the possibility of permanent monitoring of the metal bath and electric arc.

The addition material used was a full 1.2 mm diameter wire. Throughout the welding period, the base material was preheated and kept at a temperature of at least 150°C. This was possible using a 6-channel thermal treatment station and 18 bed-type resistors [4]. The parameters of the welding process were the following [7]:
- \( I_s = 180 \text{–} 210 \text{ A} \)
- \( U_s = 21 \text{–} 23 \text{ V} \)
- \( V_s = 35 \text{–} 40 \text{ cm / min} \)
- \( E_l = 679245 \text{ J/m} \).

4. Innovative solution for increasing operational safety

Since most of the spindles break in the same area, in the connection area, finite element verification has been performed. The part was drawn in CAD software and then loaded with the mechanical stresses in operation [5].

Following the analysis with finite elements, the following results in the connection area were revealed:
- a) relatively large deformations, 7.54 mm (figure 10);
- b) high internal stresses \( \sigma = 255.68 \text{ N/mm}^2 \), (figure 11).

In order to reduce the high values of stresses and deformations in the connection area, the area where most of the cracks of the spindles were produced, several design variants were tested by applying gussets with different geometric shapes, sizes and different in number [8].
After a first optimization, it was concluded that 20 mm thick gussets could be placed in 16 pairs (figure 12). After applying this variant, the values of the deformations and stresses in the connection drop to a value of 80 N/mm² (figure 13) and the total deformations fall below 3mm (figure14). The maximum values of the trains migrated to the new structure, in gussets (figure15) [9].

**Figure 12.** Gusset spindle.

**Figure 13.** Gusset spindle deformation values.

**Figure 14.** Distribution of stresses in the gusset spindle.

**Figure 15.** How to place gussets.

5. Conclusions

This article presents the MIG welding repair technology of the mill spindles as well as the constructive solution for increasing the safety in their operation.

During the operation of rotary drum mill spindles, typical cracks and metal breaks occur, which require the design of a welding repair technology. Most often cracks appear in the connection area and propagate approximately circularly leading to a rupture of the spindle in the course of time. The most stressed area is the transition from the truncated cone geometrical shape to the cylindrical shape.

The design of the repair technology has as main elements: removal of the cracked area, machining of the subassemblies, design and execution of the compensating ring, design and execution of a centring device, welding of the components. Due to the centring device designed and constructed, the deviation from the concentricity was within the prescribed limits (being only 0.5 mm, a very good value considering the overall dimensions of the parts, 3.5 m).

The solution adopted to increase operational safety resulted from the finite element analysis of some possible reinforcement constructive variants using the ANSYS modelling software. Applying this variant, there was a substantial reduction of the deformation values (40%) and the connection stresses (60%), the stresses reaching 255 N/mm² at a value of 80 N/mm² and the total deformations decreasing from 7.54 to 2.98 mm. The safety coefficient in the most stressed area increased from 0.33 to 5.

After changing the geometric shape, it has been found that the stress values have decreased by 60% and their maximum values are found in another area, namely in the reinforcing area, thus increasing the safety in operation and the life of the product.
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