Study of Wear Mechanism in the Contact between Table Liner and Roller of Vertical Roller Mills

指導教員

主査　堀尾　健一郎　教授

副査　山本 浩　教授

副査　金子　順一　助教

埼玉大学大学院　理工学研究科　機械科学系専攻

機械工学コース　機械工作研究室

10MH134　カマル　アリフィン

Table of Contents

1. Introduction

For several decades the cement industry has successfully utilized Vertical Roller Mills (VRM) for grinding of raw materials and solid fuels. The VRM offers several benefits compared to the ball mill in regards to operating costs and flexibility. Traditionally, the closed circuit ball mill with high efficiency separator has been the most common system for cement grinding. However, as happened with raw grinding over the last 25 years, the vertical roller mill (VRM) is now successfully being used for many clinker grinding applications and is rapidly becoming the standard for new grinding installations.

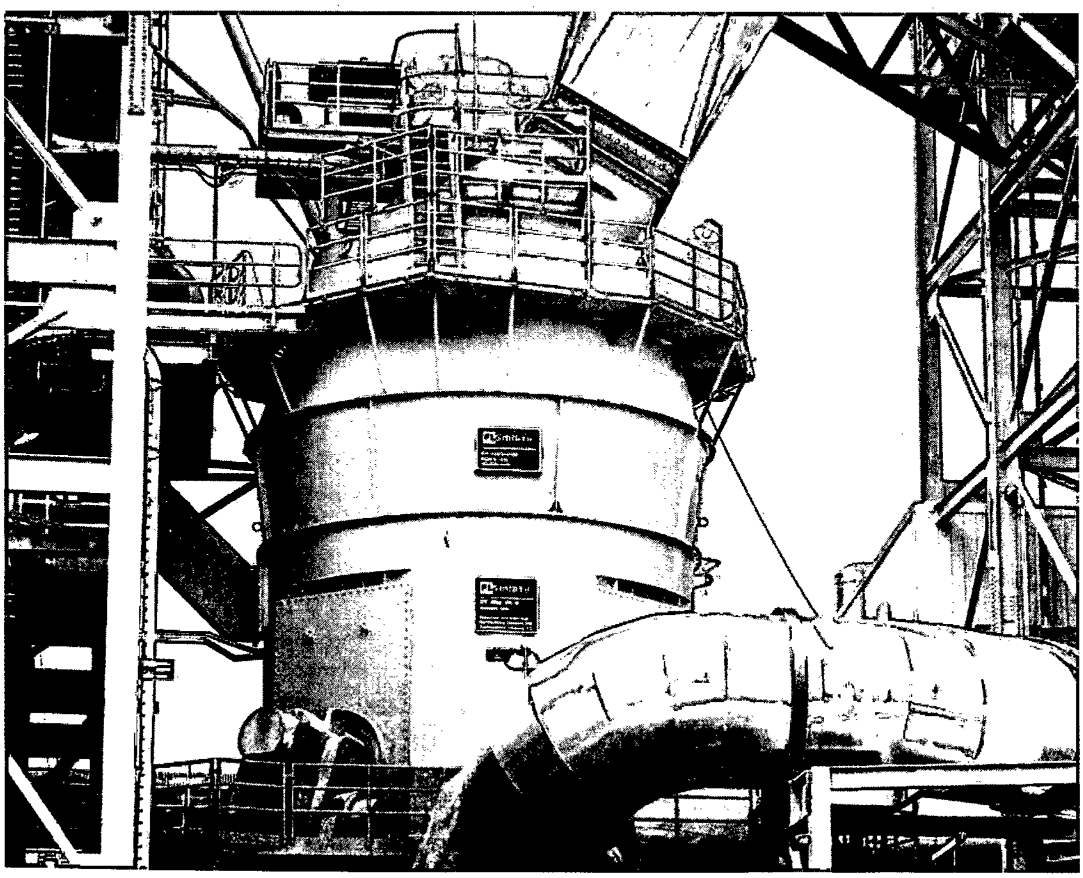

Fig. 1 OK Mill

1.1. Vertical Roller Mills (VRM)

1.1.1. Performance

Liners and mill internals for the first compartment have typical lifetimes from at least two years to around 5. Parts for the second compartment last even longer, typically from around 4 years to around 9 years.

Especially for a vertical roller mill the performance will deteriorate as a consequence of progressive wear of the grinding parts. This, however, is not only reflected in a reduced capacity, but also in higher specific energy consumption and a higher level of mill vibrations. The wear rate measured in gram per ton of cement produced is much higher for a ball mill than for a vertical roller mill.

1.1.2. Maintenance

Works for remedy of progressive wear of the grinding parts for a vertical roller mill may involve reversal of roller segments, hardfacing of roller and table segments and/or eventually replacement of worn out parts. However, the wear rate for grinding parts of a vertical roller mill grinding OPC is fairly low and maintenance of wear parts, i.e. reversal, hardfacing or replacement, can usually be scheduled to take place say once per year to follow the plant's kiln maintenance program.

For a vertical roller mill grinding a similar product, the cost of wear parts depends on the maintenance procedures, i.e. whether hardfacing is applied. If hardfacing is not applied the cost is as for the ball mill, i.e. 0.15-0.20 EUR per ton of cement. If hardfacing is applied, the corresponding figure will be 0.10-0.20 EUR per ton of cement.

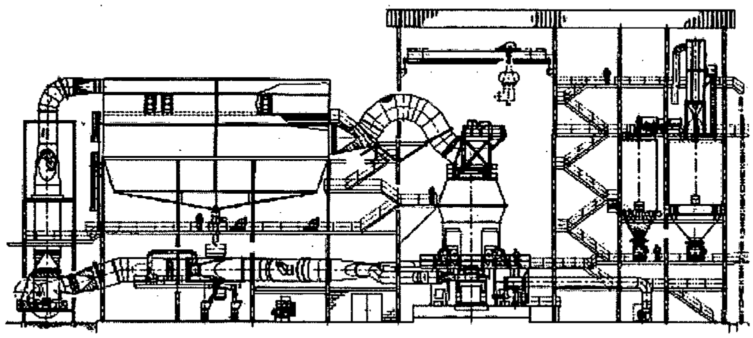

Fig 1.2 Layout of portland cement plant

1.1.3 Structure and hardfacing segment

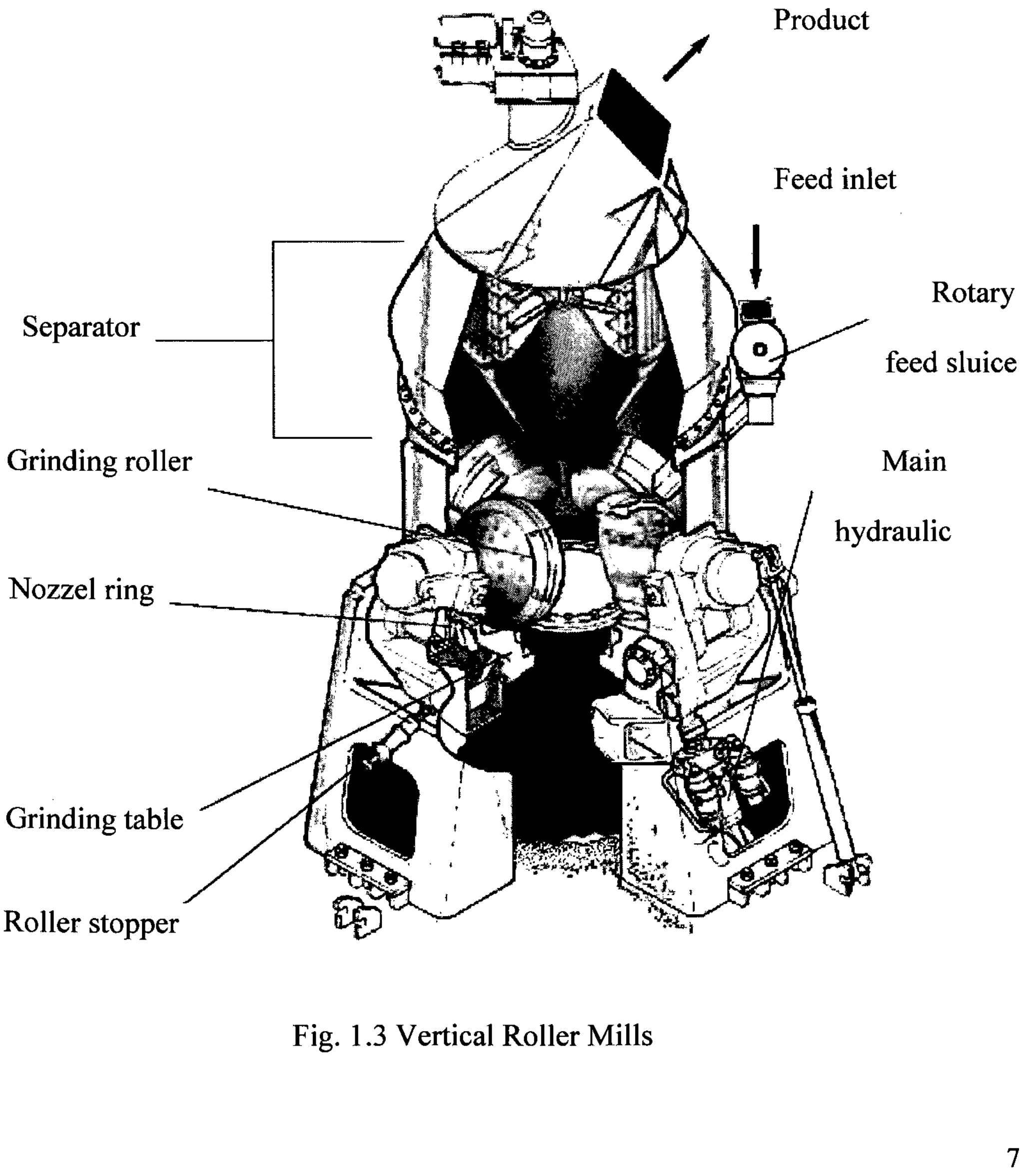

Fig. 1.3 Vertical Roller Mills

1.1.4 Vertical roller mill Work Principle

The motor drives the grinding table through decelerator. The materials fall down the centre of grinding table from feed opening. At the same time, hot air comes into the mill from the air inlet. Due to the centrifugal force, materials move to the edge of the grinding table. The materials are pulverized by the roller when by-pass of the groove on the grinding table.

The crushed materials are brought up by vane high-speed airstream, the larger particles fall down to the grinding table for regrinding. When the materials in the airstream pass the separator on the top of the mill, the coarse powder fall down the grinding table for regrinding under the function of rotation rotor.

The fine powder comes out with the airstream, and is gathered by the dust catcher. The materials content with moisture will be dried when they meet the hot airstream. Through adjusting the temperature of the hot airstream, vertical roller mill can meet different material's requirement, and also through adjusting separator, it can reach proper fineness of materials.

1.1.5 Wear liners

The wear liners of the grinding table and the rollers are of the segmented type and are therefore easy to replace when worn out. For mills grinding very abrasive materials, like slag, hardfacing is an interesting and viable means of achieving a high availability of the grinding system, optimizing the grinding process and saving refurbishment costs. Hardfacing is an economical alternative to changing wear parts and is very suitable for the high chrome cast iron grinding parts used in the vertical roller mill. Being of the segmented type the wear liners can be hardfaced numerous times throughout their life.

1.2 Advantages

1.2.1 Application advantages

Proven commercially, the vertical roller mill is the premier roller mill for finish grinding of portland cement, slag and blended cements. With a 30-45% reduction in the energy requirements for cement grinding and 40-50% for slag as compared with traditional ball mill operations, the vertical roller mill can contribute significantly to your profitability and competitiveness.

The design combines the drying, grinding and separation processes into just one unit, thus simplifying the plant layout. A low noise level makes outdoor installation feasible, substantially reducing civil construction costs and improving the working environment. Because of its highly effective drying performance, the vertical roller mill is a natural choice for grinding blended cements with one or more wet components.

1.2.2 Design advantages

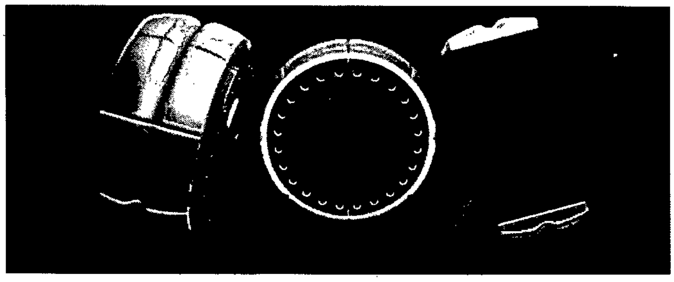

Fig. 1.4 Roller

The vertical roller mill uses a hydro-pneumatic system to press its grinding rollers against the material bed on the rotating grinding table. The grooved roller profile has two grinding zones, an inner and an outer. This creates a high and concentrated grinding pressure on the outer path, allowing air to escape into the grooved center. The inner path serves to prepare the grinding bed, by compressing the feed material as i moves under the rollers into the high pressure grinding zone. Segmented roller wear parts are made of the hardest possible material without risk of cracking and are very well suited for hard facing. Re-positioning of rollers is possible for evening out wear These features ensure maximum longevity.

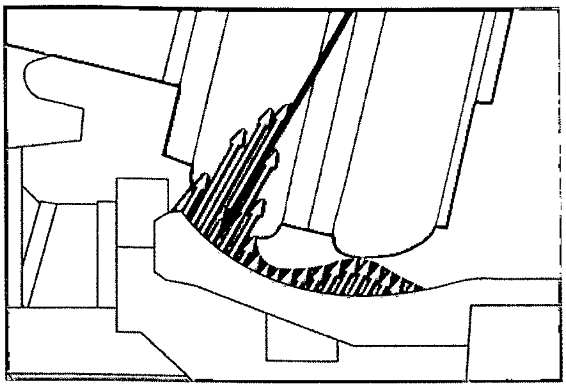

Fig 1.5 Rollers

As shown in Figure 1.5, the rollers of the OK mill are spherical in shape with groove in the middle. The table is also curved forming a wedge-shaped compressio and grinding zone between the rollers and the table. This dual-lobed design is optimur for clinker grinding because it supplies two distinct grinding zones – a low pressur zone and a high pressure zone.

1.2.3. Operating advantages

The rollers are in a lifted position when the mill is started, ensuring trouble-free start-up. This eliminates the need for an auxiliary drive. A control system monitors the machinery and facilitates operation.

1.3. Objectives

A demand for fine or ultrafine particles is increasing in many kinds of industries. The energy efficiency of comminution is very low, and the energy required for comminution increases with a decrease in feed or produced particle size. Research and development to find energy-saving comminution processes undoubtly need to be performed.

The wear process of VRM is integrally affected by various factors, such as abrasive wear, oxidation wear, cracking by thermal fatigue and heat impact, fatigue wear, and sticking of rolled material onto the roller surface. Wear also involves microscopic and dynamic processes occurring at interfaces between the roller and the rolled material, and is almost impossible to observe directly. It has been reported that raw material VRM wear parts need servicing at intervals between 4 months and 10 years. Wear rates exceeding 10 g/t will result in unsatisfying production rates and the maintenance costs will become excessively large.

This study is aimed at identifying the most common degradation mechanisms occurring in closed circuit high stress comminution equipment such as VRM.

2. Preparatory

The VRM is a commonly known grinding unit in the cement industry. The VRM sizes range from approx. 2 to 6 m in table diameter, and depending on the VRM size, the feed material will vary between pebble sized rocks in small VRMs and Ø150 mm fragments in large VRMs. The final product will typically be classified or separated at 12% + 90 mm. Contrary to clinker VRMs the mineralogy of raw materials varies significantly making the process difficult to predict and control. The grinding process is highly heterogeneous as the raw mix on average is made up of 3 very different minerals (for instance limestone, clay, quartz) with different cohesion, particle size distributions (PSD) and hardness properties:

Due to the mineralogical differences the power consumption will range between approx. 3 and 11 kWh/t. Due to the advantageous centrifugal forces, the VRMs are normally operated at 20–40 rpm depending on the VRM size and this will yield a maximum tangential speed of approx. 7 m/s in large VRMs. The table is driven by an electrical motor and the rollers rotate due to the frictional force established in the grinding bed.

The grinding force is made up of the net weight of the rollers and an additional hydraulic force. In the VRM, several separation processes controlled by the air flows will change the mineralogical composition of the grinding bed. VRMs are mainly used in the cement and coal industry as a 3in1 machine (grinding, separation and drying). However, if laboratory measurements indicate wear rates significantly above 10 g/t, a ball mill (tube mill) will be chosen as the most economical solution: Experience shows that wear rates exceeding 10 g/t will result in unsatisfying production rates and the maintenance costs will become excessively large. It has been reported that raw material VRM wear parts need servicing at intervals between 4 months and 10 years.

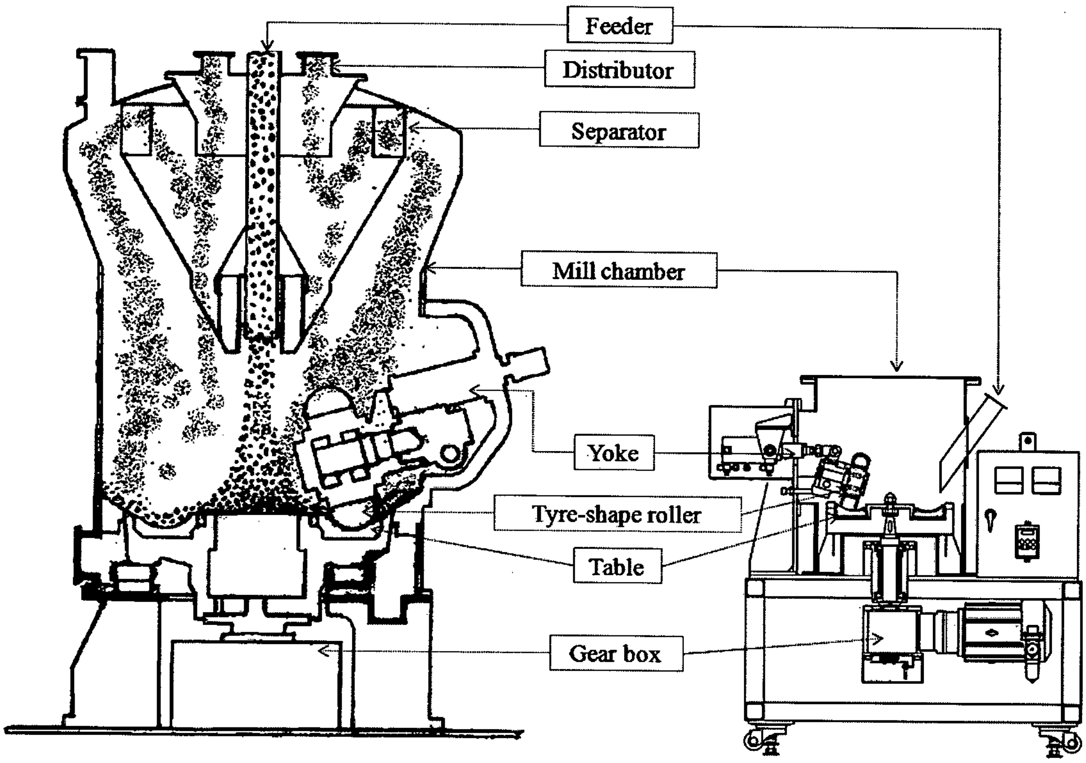

Fig. 2.0 Comparison between VRM

The experimental VRM has the exact same dimensions as the standard laboratory VRM and thus represents an exact downscaling of a large industrial VRM. The VRM has a table diameter of 300 mm and a total height of approx. 1500mm.

The VRM has mill housing, no separator and is equipped with only one roller for more clearance and ease of testing. Both the roller and the table are fitted with several spokes to ensure adequate mechanical strength during testing. The VRM is equipped with a 750W asynchronous motor, a 1/20 transmission and a frequency converter 175rpm (0–120 Hz) to control the speed. The height of the dam ring is fixed and the tow-in angle can be adjusted. The roller is mounted on a yoke to imitate the FLSmidth OK27-4 VRM setup where a free moving yoke supports the three rollers. The height of the yoke can be adjusted in order to change the camber angle of the roller. The VRM is operated at subnominal speeds (0–70% of nominal speed) in order to avoid dusty conditions. At approximately 70% of nominal speed, the material will just stay within the dam ring without leaving the table as a result of centrifugal forces. Pressure was varied between 0.1MPa and maximum 0.7MPa.

2.1 Equipments

2.1.1. Table Liner

2.1.1.1 Design and technical preferences

As mentioned before, normally table liner is divided with many partitions ranging from 3 to 16 partitions. There are many type of shape for table liner such as cone-shaped and plane-shaped. Those shapes will influence on how hardfacing welding process will be operated. Table liner usually made from high-chromium cast iron, carbon cast steel, steel casting for welded structure and high-manganese cast steel. It is important to choose the right welding method according to the material, and especially for hardfacing welding process material from high-chromium cast iron is most preferable. For this study, the material used is stainless steel SS400. The main reason why this material was chosen mainly because due to its machinability.

Diameter for table liner is 300mm and its height is 40mm. On the surface, there are R55 curve with 90mm long. To prevent table liner from any movement and to maintain its position during rotation, on the outer diameter oblique side with 10°were created to fix it with dam ring. The dam ring then were fixed at the outer diameter with 12 pieces of bolt In the middle, to add more force in order to maintain it to the position a 120mm diameter cup were attached to the 10°tilted surface and strengthen with bolt.

2.1.1.2 Machining

Machining process was beginning with machining centre with ball end mill tools. First 20mm diameter of hole was made, followed by arc surface and then cutting of middle height to 35mm. In order to maintain table liner flatness even after hardfacing welding process, the width was cut little bit bigger from 45mm to 50mm.

After hardfacing welding process finished, machine work were done at the middle with φ120 ±0.2 and the bottom surface were cut -5mm and for the side surface were cut -5mm for one side. After hardfacing welding process inspection were made and comparison of before and after measurement to check any strain or distortion.

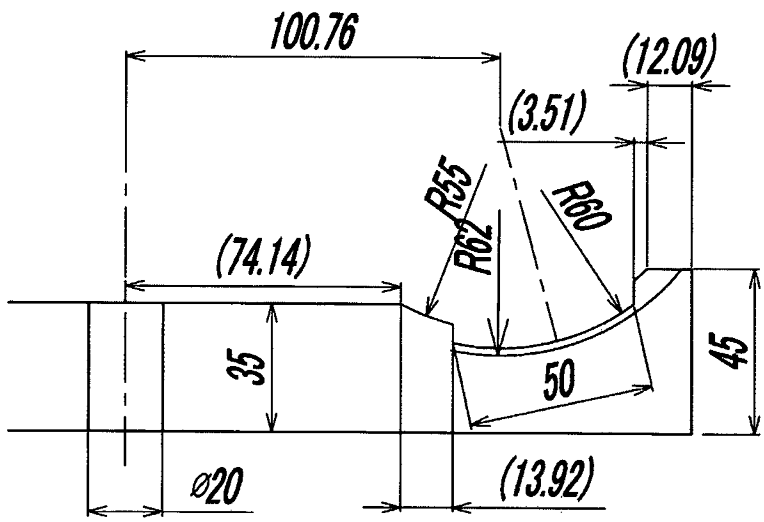

Fig. 2.1.1 Design figure of table liner

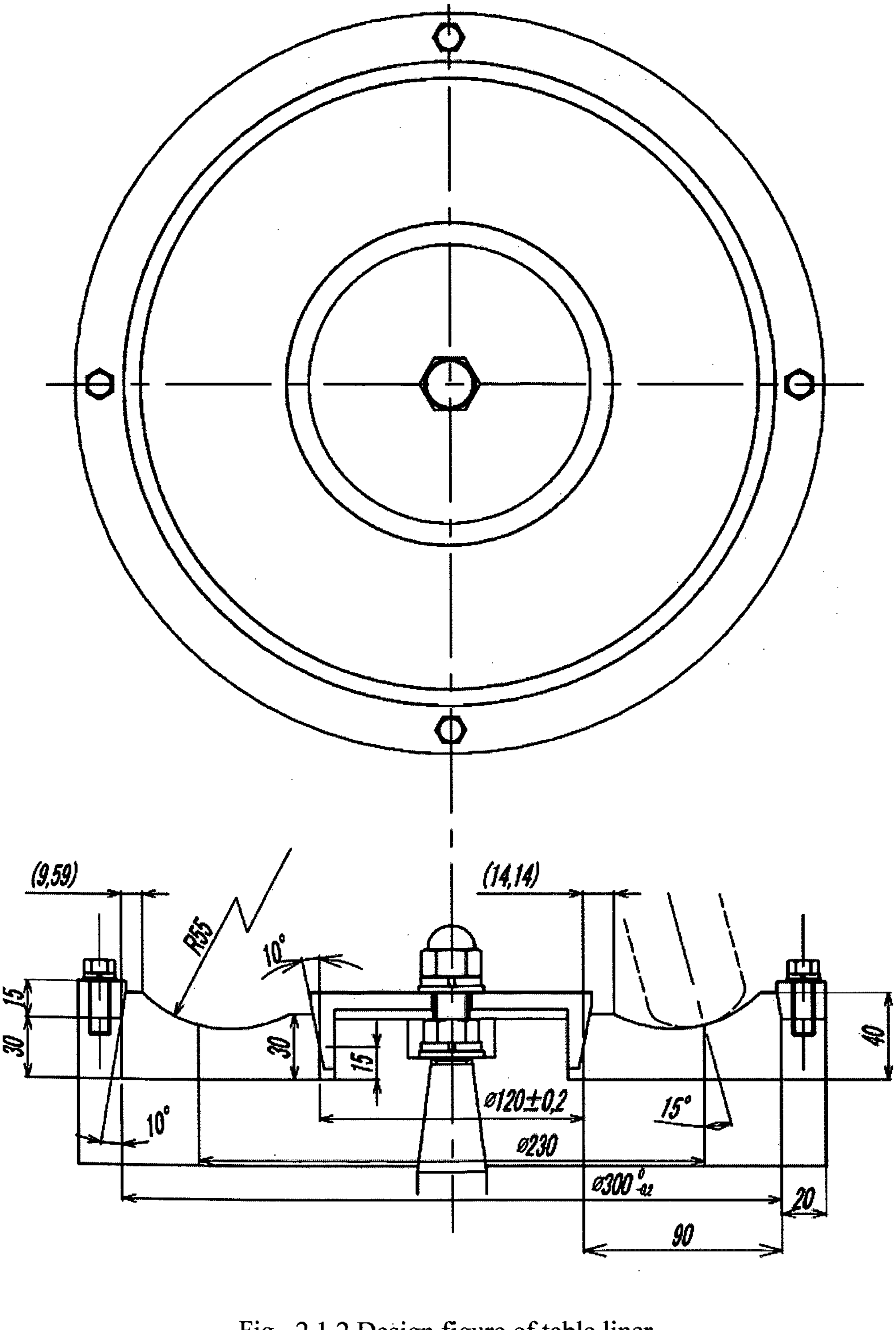

Fig. 2.1.2 Design figure of table liner

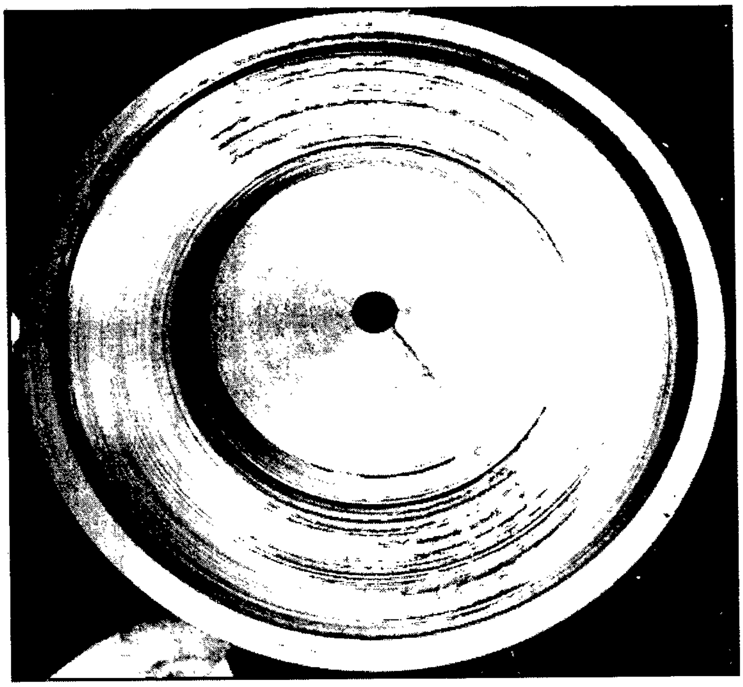

Fig. 2.1.3 Table liner

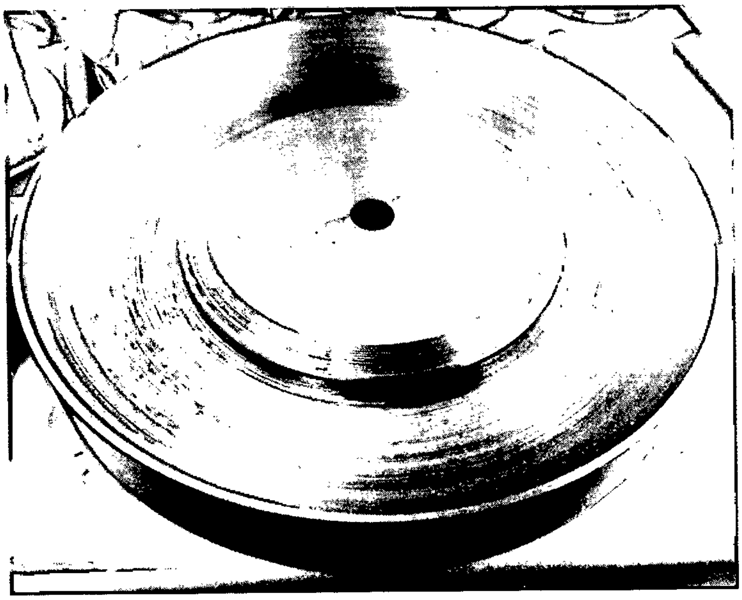

Fig. 2.1.4 Table liner

2.1.1.3 Hardfacing

Condition of construction;

- Welding wire: MILL100 φ1.6(5%C-25%Cr-etc)
- Welding equipment: WAMS D2-Pendant System and small positioner
- Used wire weight: Approx. 2kg

Table 1 Hardfacing condition

	1st Layer	2nd Layer
Pass number	13 pass	11 pass
Voltage	28V	28V
Welding speed	1000mm/min	1000mm/min
Wire speed	6m/min	5m/min
Temperature between pass	Below 100°C	Below 100°C
Extrusion length	20mm	20mm

Referring to the table above, welding circumstances of table liner was done at welding voltage of 28V, welding current of 240A, welding speed of 1000mm/min, temperature between pass at below 100°C and hardfacing pass number for 1st layer is 13 pass and 11pass plus 2pass for 2nd layer. It takes 2 days with 3hours of preparation and 3 hours of welding on the first day and 3 hours more for the second day.

After finishing welding process, by using laser measurement equipment, shape of table liner was measured.

There are some problem occurred during welding process. The problems are firstly during 2nd layer welding process at the edge of outer circumference for the laye of hardfacing iron and table liner were skinned. It is learned that the breaking measure at 0.5mm and some clear aperture were seen. This problem was repaired by using TIC welding method with SUS308 material. Remaining small aperture was repaired withou using welding material but by using meltran. After repairmen, by using MILL100 at 1-: pass hardened hardfacing welding were done and followed by finishing by usin grinding.

Secondly, the problem is the table liner were displace from its middle poin making aperture happen at the edge of table liner and welding area. This problem wa settled by adding 1 pass more to the table liner. Adjustment for positioned were done.

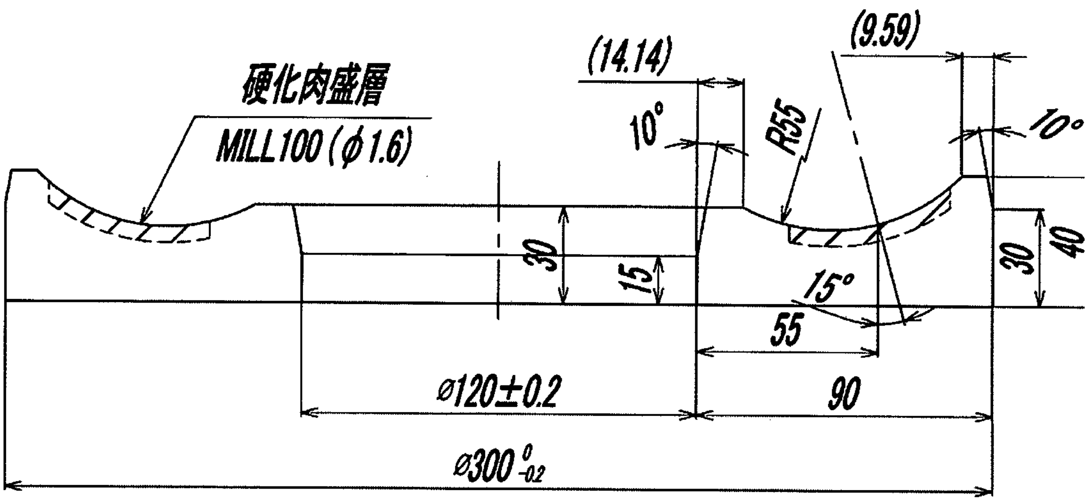

Fig. 2.1.5 Hardened layer

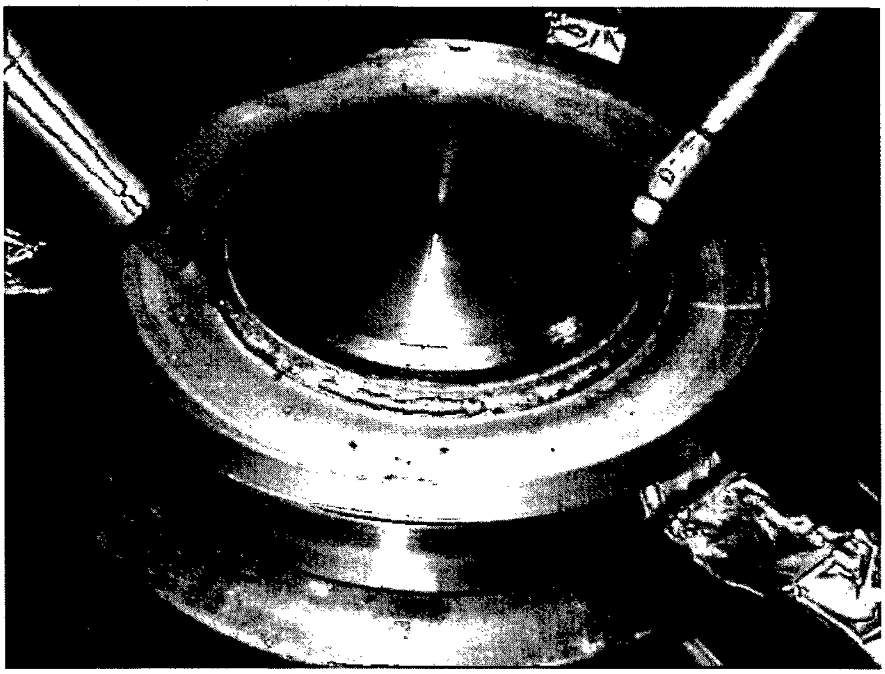

Fig. 2.1.6 Hardfacing

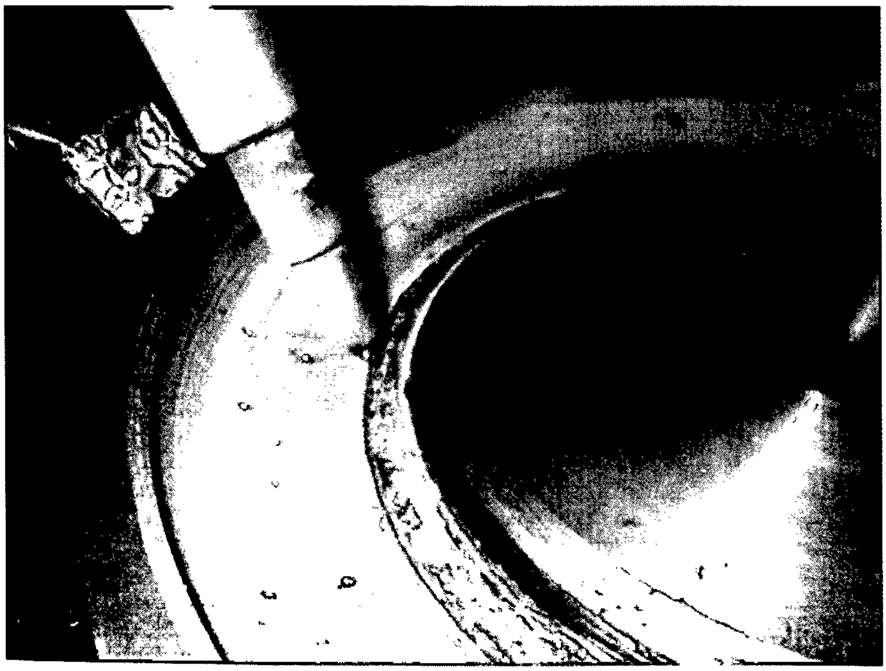

Fig. 2.1.7 Hardfacing

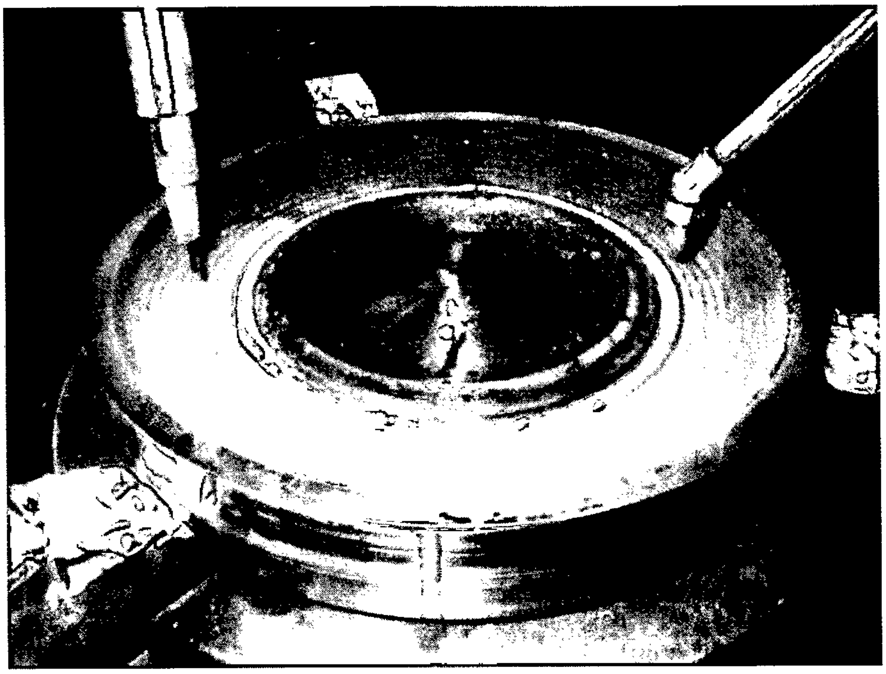

Fig. 2.1.8 Hardfacing

Fig. 2.1.9 Open crack

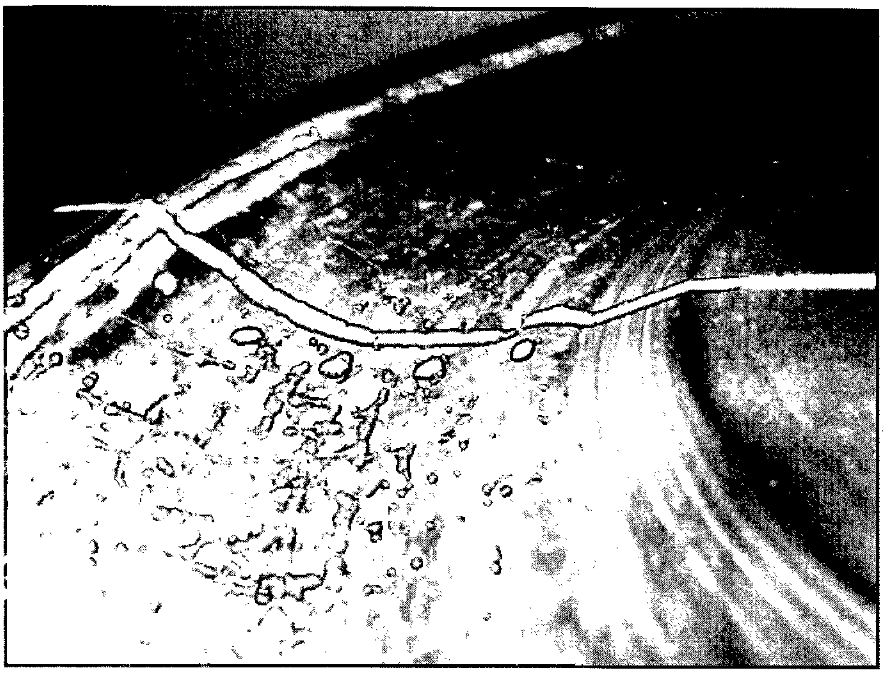

Fig. 2.1.10 Measurement

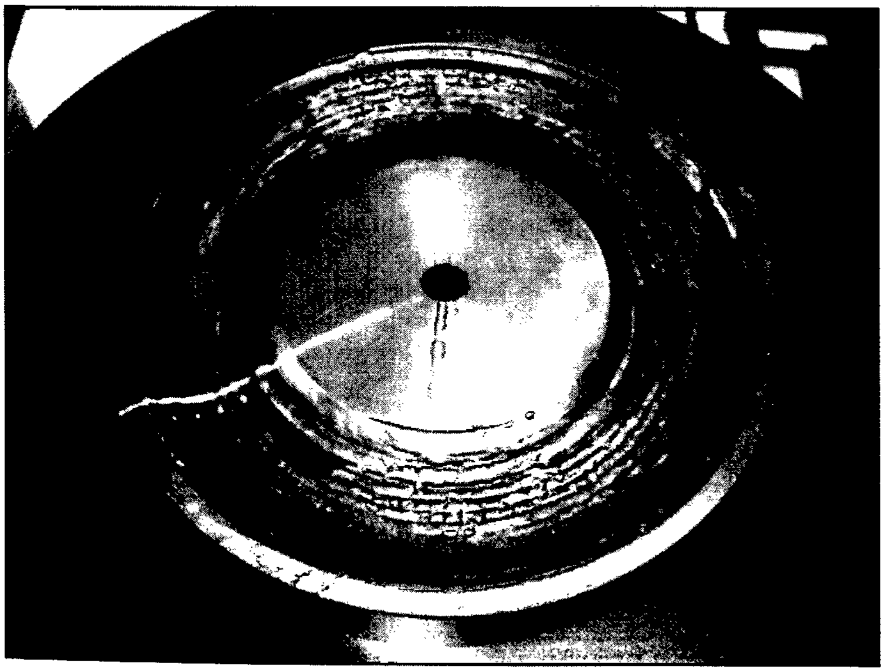

Fig. 2.1.11 Laser measurement

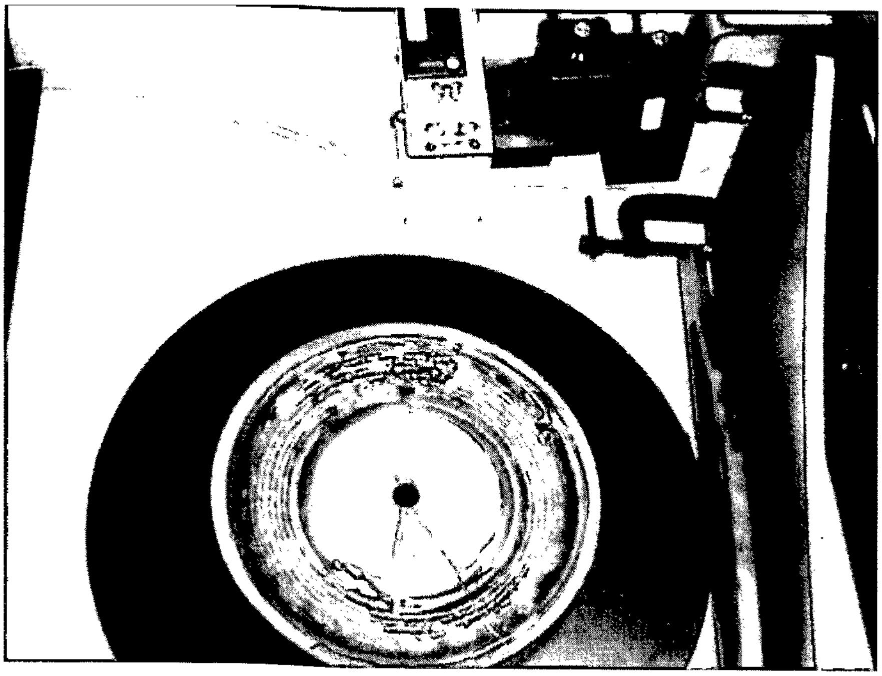

Fig. 2.1.12 Laser measurement

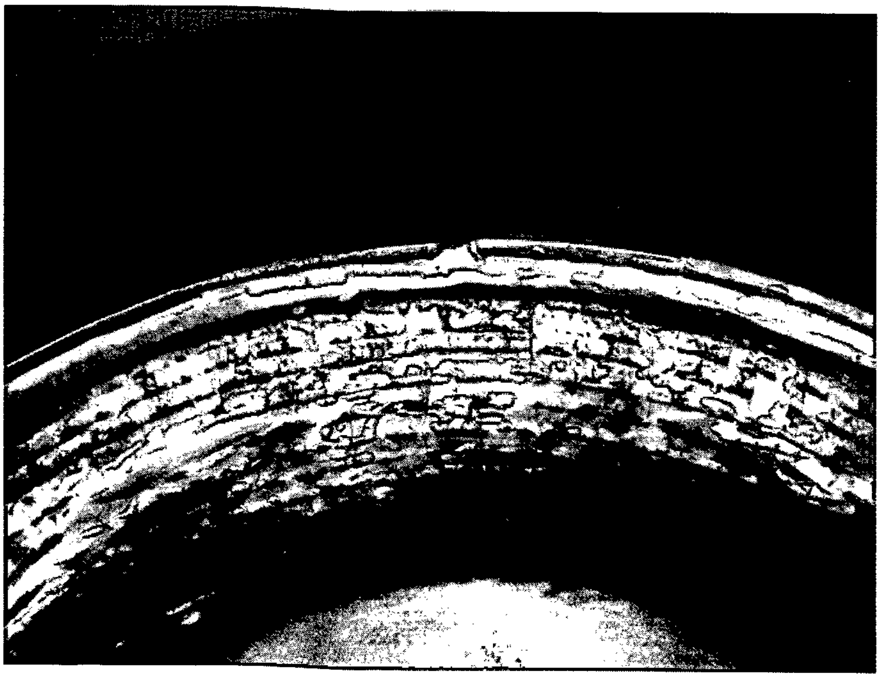

Fig. 2.1.13 Bit layer

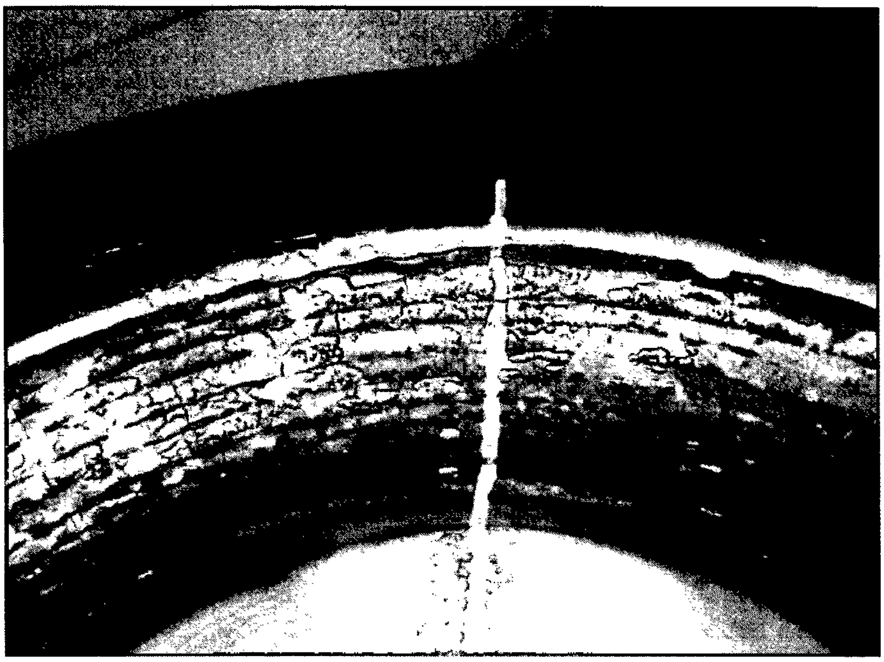

Fig. 2.1.14 Counting layer

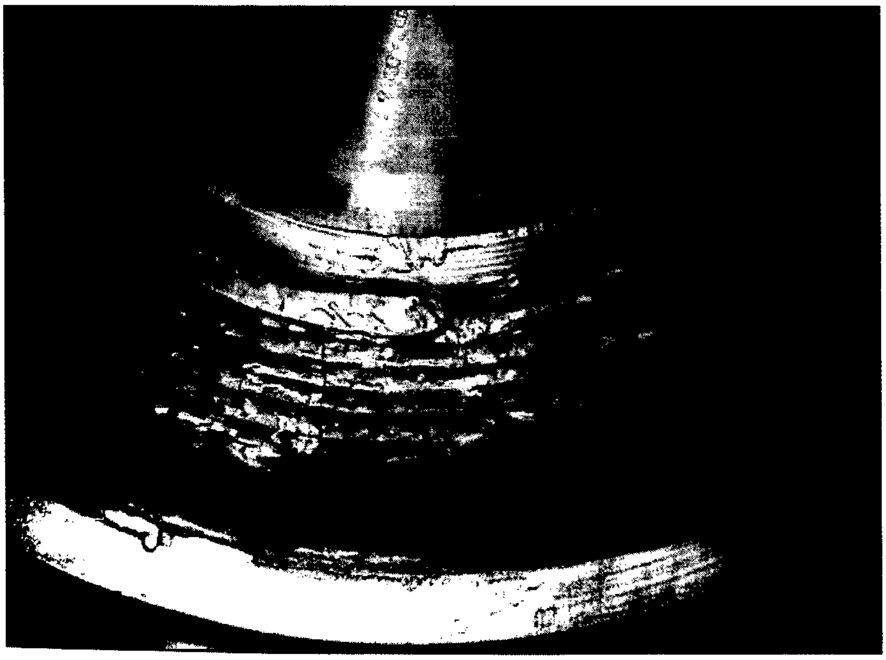

Fig. 2.1.15 Double layer

2.1.2. Roller

2.1.2.1 Design and technical preferences

On the real machine, normally the number of roller varies from 2 until 4 pieces Moreover, roller is held by supporting axis, that allowing vertical movement and als creating clearance space on table liner. Rollers' type can be classified into tyre-shape circular truncated cone-shape, long cylinder-shape and ball shape.

Additionally, roller also can be divided into two types which are integrated typ and split type. Roller usually made from high-chromium cast iron, carbon cast stee steel casting for welded structure and high-manganese cast steel. It is important t choose the right welding method according to the material, and especially fc hardfacing welding process material from high-chromium cast iron is most preferable For this study, the material used is stainless steel SS400. The main reason why thi material was chosen mainly because of its machinability.

Diameter for roller is 150mm and width is 45mm. The outside surface is curve with R40. In the middle a hole with diameter φ65mm were drilled. This roller will b welded with hardened hardfacing MILL100φ1.6mm with the width of 35mm. Heigl for welding layer will increase roller diameter to R45. For finishing machining, at th both side, hole with outer circumference of φ100mm and inner circumference of φ8 and depth 7mm were machined. This allows 8 pieces φ5.5mm screw to be installed t maintain roller to the yoke.