Redesign Of A Grinding Mill For The Minimisation Of Iron Filing Production

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ABSTRACT: The local food grinding mills in usage across the country are characterized by the production of iron filings as part of the grounded food meant for human consumption. The filings of iron when taken into the body create health problems such as *hemochromatosis* leading to *hepatoma*, the primary cancer of the liver. The root causes of the production of iron filings were determined based on existing design of the grinding mill. Therefore, it is imperative to improve and redesign a grinding mill that will eliminate or minimize the iron filings production that get into the human digestive system which is associated with health problems. In this paper, we redesigned a new grinding mill, by employing the use of a misalignment detecting sensor and signalling apparatus together with the incorporation of a permanent magnet to drastically minimize if not totally eliminate the iron filings. Conclusively, the new grinding mill is more human friendly as it can not contaminate ground food stuffs with iron filings. [Researcher 2010;2(7):60-77].

KEY WORDS: Grinding mill, Iron fillings, health problems, *hepatoma, hemochromatosis,* existing design of mill, grinding mill redesign.

INTRODUCTION

Relevance of iron to the human body has been investigated by many a researcher. Much of these works are confined to issues of iron deficiency in the body. Iron deficiency is known to lower cognition in humans especially children, it affects learning, and it is considered as a nutritional problem that needs to be prevented and treated (Hulthen, 2003). Iron serves as the key ingredient for healthy red blood cell production, it is the main component of hemoglobin which carries oxygen round the body and iron deficiency anaemia is considered a common problem for people with kidney disease (DPC, 2008, AAKP, 2005,). To keep the immune system healthy and promote normal brain cell functionality, iron is needed (Hillan and Bobroff, 2006). At the opposite end of the spectrum however, is the phenomenon of iron overload which occurs mainly as a result of overabsorption, overconsumption and overretension of iron. Health disorders such as arthritis, diabetes, psychiatric illness, liver disease, cancer, heart disease, thyroid disease, infertility are related to excess iron in the body (Cutler, 1994, Brody, 1997, Robinson, 1995). Both cancer cells and infectious organisms needed iron from their host to grow. They cannot multiply without iron and oxygen from the blood.

Duly reported in the literature are tobacco leaves, foods and supplements as rich sources of iron. Also, iron can be inhaled; hence smokers of tobacco leaves, asbestos workers and people who grind or weld steel, mine iron or paint with iron oxide powder could acquire high levels of iron in their lung tissues. These increase their risk of lung cancer since they spew particles containing iron into the air and partly because their lungs are chronically exposed to the spewed excess iron (Brody, 1997). Comparatively, there has been minimal focus on iron filings in grounded food material as a potential source of iron overload. This is partly due to the minute nature of the filings and more so the way and manner the food substance is grounded by way of the grinding mill. The body has only one way to rid itself of excess iron, through bleeding, which is why symptoms of iron overload are rare in menstruating women until after menopause (Brody, 1997). In this paper, we established the occurrence of iron filings in grounded food as a result of an inappropriate grinding process and misalignment of grinding surfaces; we redesigned the grinding mill to curtail iron filings production.

Very gradually and slowly our health is being degraded by certain ways that we process our foodstuffs. This, we hardly realise. Most grinding mills are designed such that for a fine texture of the material (e.g. corn, groundnuts, tomatoes and so on) the operators must adjust the grinding plates to be so close together that they more or less make contact with each other. With such an adjustment iron filings are realised as part of the grounded material. The iron filings are very fine in nature and therefore are not easily seen in the grounded material. It is therefore consumed as part of the food. The adverse result of this is a consequence of gradual future health problems.

An experiment was conducted to confirm the existence of iron filings in ground food flour. Three different half bowls of corn were grounded in three different stages; each stage for a particular bowl of the corn and the stages correspond to a distance of gap between the grinding plates of the mill. A magnet was used to stir the grounded corn for the three different bowls of corn flour obtained after the grind. The volume of filings accumulated or attracted by the magnet was noticed and scraped off the magnet on a white plane sheet of paper. Pictures were taken.

For stage one, the distance between the grinding plates was quite large. It was realised that no trace of filings were seen on the magnet after the grounded corn was stirred with the magnet. For stage two, the distance between the grinding plates was made a little closer than before but there was no contact between the plates. The result after the stir was not different from the first stage. What construed in the last stage when the adjustment on the gap in between the plates is almost zero, that is to say the plates made contact to each other, was that some filings of iron were attracted by the magnet. The magnet was used to stir the corn flour several times and each time the attracted filings were scraped off onto the plane sheet of paper.

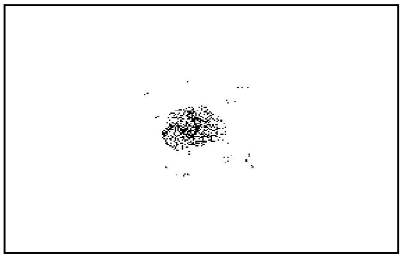

Fig. 1 Iron Filings obtained from Grinding Half a Bowl of Corn

Analysis of Experimental Results: It was realised that iron filings were accumulated with the finest grind of the corn which was gotten at stage three. If half a bowl of corn at the finest grind gave out that much of iron filings then for the consumption of a family of about six (6) people, about three bowls would be grounded and that means more iron filings. Even for the half bowl of corn flour, there are still more iron filings which were not attracted because the experiment was carried out to ascertain the truth that indeed iron filings are in the grounded food but not to get out all the filings of iron. One can therefore imagine the amount of iron filings that gets into the human body from the grounded food taken.

This experiment proved two things:

- Indeed, there are iron filings in the food that is consumed
- The contact made by the grinding discs is what produces the iron filings

Presence of iron filings in grounded food substances was reported in the literature. Francis (2004) conducted two experiments using wheat flour or cereal, water, zip-lock plastic bag or bowl and a magnet to discover presence of iron particles in grounded food material.

Iron Filings and its Health Hazards to the Human Body: Iron filings produced as part of the grounded food as a result of the grinding teeth rubbing each other has some long term health effects on the human body.

Iron and Iron Toxicity: Iron is an essential nutrient found in many foods. The greatest amount is found in red meat and iron-fortified bread and cereal. In the body, iron becomes part of haemoglobin, a molecule in the blood that transports oxygen from the lungs to all body tissues. Healthy people usually absorb about 10 percent of the iron contained in the food they eat to meet the body needs (Andrews, 1999, Anon, 2005)
The toxicity of iron is governed by absorption. The more you take in the more you are at risk. The iron is absorbed in the ferrous state by cells of the intestinal mucous. Gastric and intestinal secretions can reduce ferric ions (the unusable form of the iron) to the ferrous (absorbable) state. Ferrous iron reacts with hydrogen peroxide (H_20_2) to form OH, in the reaction:

$Fe(II)+H_2O_2\text{-->}OH+OH\text{-}+Fe(III)$ ……... (1)

Under normal conditions, the free radicals formed are controlled and removed by antioxidants, but for an over abundance of iron in the body, the free radicals will not be removed fast enough causing a build up.

Diseases that can Cause Iron Toxicity: Iron toxicity is not always due to an increase in dietary iron. There are many diseases that can lead to a problem in iron absorption and in turn iron toxicity. With acute iron poisoning, much of the damage to the gastrointestinal tract and liver may be as a result of a highly localized iron concentration and free radical production, leading to *heptatoxicity* via *lipid peroxidation* and the destruction of the *hepatic mitochondria*. Therefore, the patient needs rapid removal of iron from the gut to prevent tissue damage. The iron-accumulating disease is hemochromatosis. Hemochromatosis, the most common form of iron overload disease, is an inherited disorder that causes the body to absorb and store too much iron. The extra iron builds up in organs and damages them. Without treatment, the disease can cause these organs to fail. People with hemochromatosis absorb more than the body needs. The body has no natural way to rid itself of the excess iron, so it is stored in body tissues, especially the liver, heart, and pancreas. (Anon, 2005, Cutler, 1994, Brody, 1997, Andrews, 1999).

This is an iron storage disease that results from the inability of the intestine to keep out unneeded iron. Instead, iron accumulates in the liver causing siderosis (the accumulation of storage iron in tissues) and damage to the storage organs. A normal man will usually absorb 1mg of iron/day, but with this disease, he will absorb 3mg/day (Cutler, 1994). This is a very common problem and one (1) out of every fifteen (15) people have a form of this disease. There are two types of this disease namely:

- Hereditary or primary *hemochromatosis*
- Acquired or secondary *hemochromatosis*

- *Hereditary hemochromatosis:* Genetic or hereditary *hemochromatosis* is mainly associated with a defect in a gene called *HFE*, which helps regulate the amount of iron absorbed from food. There are two known important mutations in *HFE*, namely *C282Y* and *H63D.* C282Y is the most important. When *C282Y* is inherited from both parents, iron is over absorbed from the diet and *hemochromatosis* can result. *H63D* usually causes little increase in iron absorption, but a person with H63D from one parent and C282Y from the other may rarely develop *hemochromatosis.* A person who inherits the defective gene from both parents may develop *hemochromatosis.* A person who inherits the defective gene from only one parent is a carrier of the disease but usually does not develop it. However, carriers might have a slight increase in iron absorption (Lee, 2009, Anon, 2005, NIH, 2007)

In hereditary hemochromatosis, the intestines lack the normal ability to keep out the available but unneeded dietary iron. Patients suffering from this disease take in the iron, but have problems excreting it. The excess therefore goes into storage. It has been shown numerous times, that with an increased uptake from the diet of 1-3 mg of iron, more than required, per day, in a period of 40 -50 years, 20 - 40 g of iron will be accumulated in the body. This accumulation especially occurs in the liver and heart, and will eventually lead to necroses and cardiopathy. This condition can be spotted at an early stage by determination of serum ferritin concentration and liver biopsy (NIH, 2007). The condition can be treated and cured if caught before the tissue damage begins.

- *Acquired Hemochromatosis:* It is an intestinal abnormality occurring with acquired diseases. Some of the diseases this may happen with are: Anaemia and ineffective erythropoiesis. These diseases may result when a patient receives blood transfusions, but receives them for too long and the iron begins to build up. If a patient has a liver disease, he will not be able to control the iron uptake from the liver and the iron will begin to accumulate. High intake of iron is also a contributing factor. Many times people are wrongly diagnosed with anaemia and they are given supplements that they do not need and the iron in their body increases.

Problems Resulting from Iron Toxicity: There are many problems that may result from iron toxicity, these include: Anorexia, oligura, diarrhea, hypothermia, diphasic shock, metabolic acidosis, and death. In addition to these, the patient may experience vascular congestion of the gastrointestinal tract, liver, kidneys, heart, brain, spleen, adrenals, and thymus. As a result of iron storage disease, the liver becomes cirrhotic. Hepatoma, the primary cancer of the liver, has become the most common cause of death among patients with hemochromatosis. Also, when siderosis becomes severe in young people, myocardial disease is a common cause of death. Impotence may occur in young men, and amenorrhea may occur in young women. Both of these sexually related problems are due to iron loading in the anterior pituitary.

Root Causes of the Production of Iron Filings: When two rough metallic surfaces rub against each other there is the production of metallic filings. The grinding disc is made from cast iron, thus iron filings are produced when the two disc surfaces rub against each other. This is what causes the surfaces to get blunt with use, hence the frequent sharpening of the grinding discs. Therefore, there is the conclusion that when the desired texture of the material is to be very fine it could only be achieved when the gap between the discs is very close as to make contact with each other and this results in the production of iron filings as part of the food consumed. This conclusion is buttressed by the experiment which was carried out to ascertain the truth that the food which is consumed really contains some filings of iron.

The root causes of the production of iron filings are three fold:

- Touching of the grinding plates
- Misalignment from the perfectly vertical position of grinding plates
- Incorrect sharpening of the grinding plates

Table 1: Causes and Effects of the Production of Iron Filings

Causes	**Reason**	**Effects**
Touching of the grinding plates	Inadequacy of operators' understanding of mill's mechanism. To them, a fine grind obtains when the plates touch hence the over operation of adjustment wheel	A vigorous and unpleasant sound of very high frequency due to metal rubbing metal is produced.
Misalignment from the perfectly vertical position of grinding plates	1. Inadequate measurement techniques 2. Degradation of or improper foundation 3. Motor vibration	1.Vibrations leading to rapid wear of couplings, bearings, seals and other rotating elements. 2. Shaft deviates from its normal, horizontal position resulting in interference, frictional heat build up and excessive wear.
Incorrect sharpening of the grinding plates	1. Inadequacy of machinist's understanding of design pattern. 2. Grinding plates become grooved in an unparallel manner	1. Unequal height and width of cutting teeth resulting in interlocking of grinding plates. 2. The barest minimum of distance is disrupted for a fine grind

The original design pattern is characterised by the serrate pattern of segments which comprises a plurality of straight, parallel ridges acting as cutting teeth alternating with parallel grooves and being so designed that the cutting teeth of each segment has a constant height and width and make such an angle with respect to the line of symmetry of the segment that the cutting teeth of each milling disk will intersect the lines of symmetry of each segment of the other milling disk at an angle of

$\pm\alpha_1$, for one milling disk and

$\pm\alpha_2$, for the other milling disk,

such that the first cutting tooth of each segment of one milling disk will intersect the cutting teeth of the other milling disk at angles of intersection K which vary according to the relationship (Anderson and Soro, 1987):

$$K = (\pm\alpha_1 + \pm\alpha_2) \pm X^{o} \quad \text{......(2)}$$

where,

α_1 and α_2 = The angle between one cutting tooth of each segment in relation to the line of symmetry.

X = The sectoral arc angle of the segment

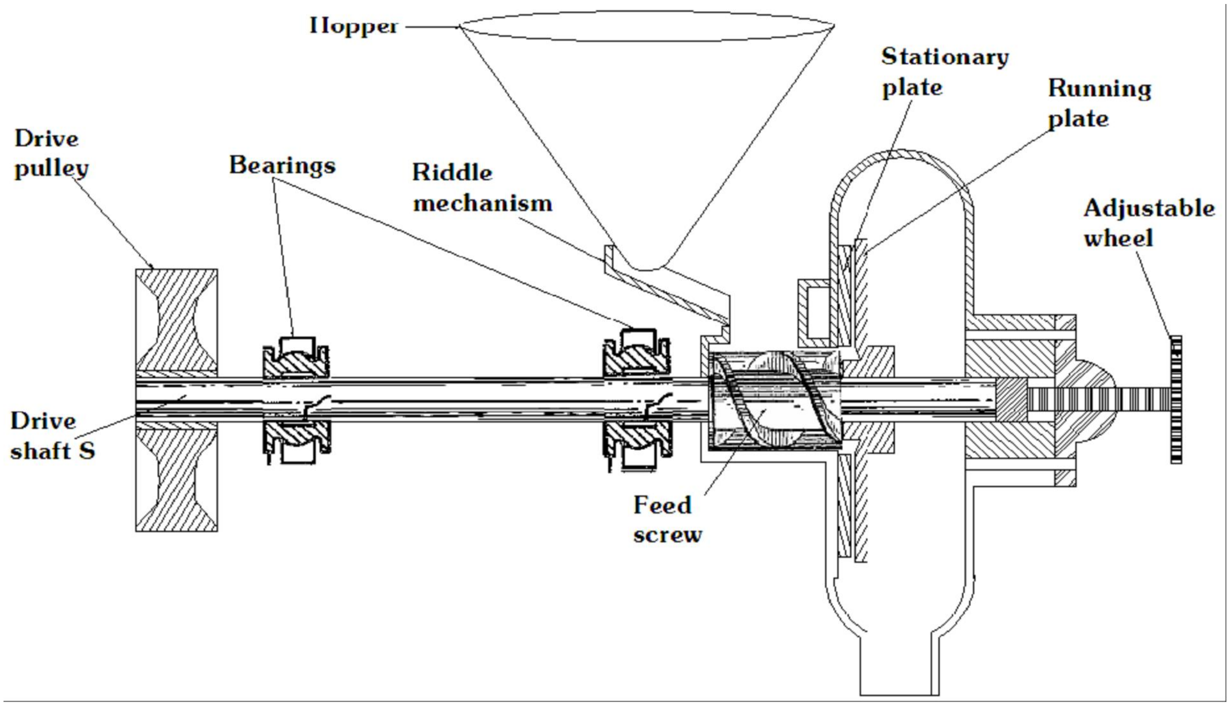

Fig. 2 Existing Design of Mill

MATERIALS AND METHODS TO FACILITATE THE MINIMISATION OF IRON FILINGS PRODUCTION

Methods and Materials to be applied in solving the problem: Having known the actual cause of the production of iron filings, a number of methods could be employed to remedy the situation.

Alignment: Positioning of something for proper performance or positioning of different components relative to one another, so that they perform properly is known as alignment in machines. When machines are assembled in sets, it is vital that all the parts are properly aligned to each other. Poor alignment will cause vibration and lead to wear of bearings, seals and other rotating elements.

Grinding the Surface of the Plate before Re-grooving: Surface grinding is a manufacturing process which moves a grinding wheel relative to a surface in a plane while a grinding wheel contacts the surface and removes a minute amount of material, such that a flat surface is created. The grinding plates are first surface ground for parallelism. A rotary surface grinding machine where accuracy of parallelism and flatness are required on raw metal, cast iron, aluminium, bronze or steel parallel surfaces is used before re-grooving of the plate when it gets blunt. Milling and to some extent, planning also produce surface grinding.

The advantages that high horsepower surface grinding provides over milling, planning or other metal cutting techniques include especially, obtaining a higher degree of dimensional accuracy and desired form of the work surface (flat and parallel to close to 0.001 inch tolerances) in a more consistent manner.

Surface grinding methods include:

- Horizontal-spindle
- Vertical-spindle
- Vertical-spindle rotary grinding
- Horizontal spindle single disk

- Vertical swivel head grinding

The horizontal-spindle rotary table surface grinding and the vertical-spindle rotary table surface grinding are geometrically more suitable for the grinding plates.

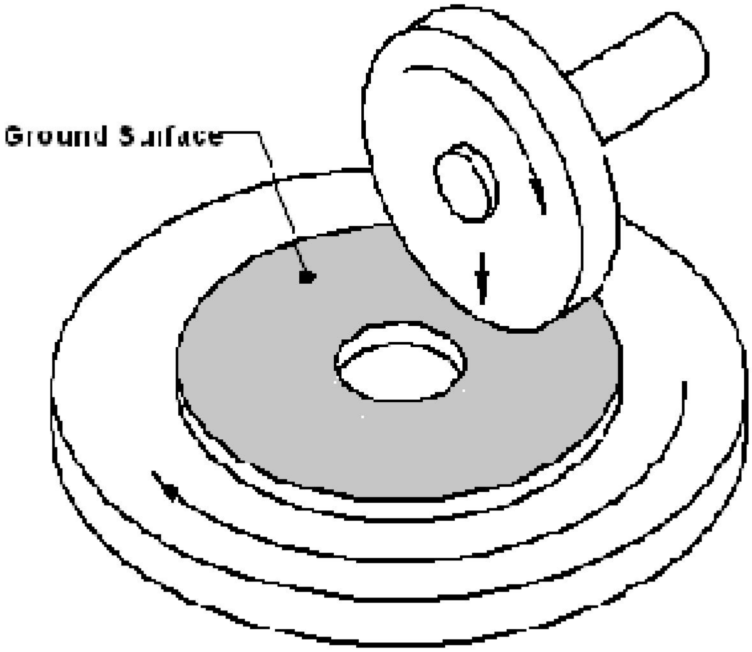

Fig.3. Horizontal-Spindle Rotary Table Surface Grinding

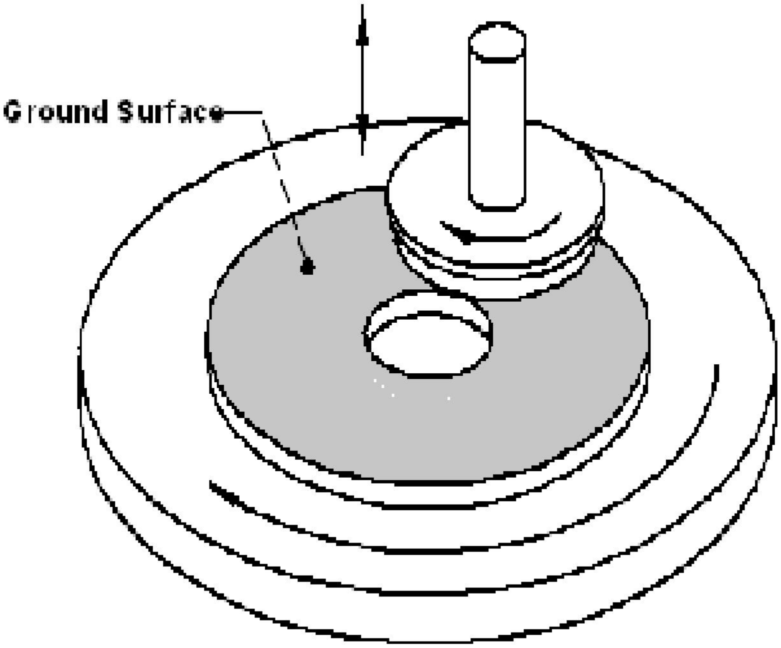

Fig. 4 Vertical-Spindle Rotary Table Surface Grinding

Use of Sensors and Signaling Apparatus to Detect Rubbing: The idea of the use of sensors in detecting abnormal conditions of operation is very advantageous. The sensors respond to physical stimuli arising out of the abnormal operating conditions only. For example an acoustic sensor could be installed on a rotating member to respond to the high and undesirable frequency sound experienced during rubbing of the grinding surfaces. Associated circuitry is required to discriminate this abnormal condition from others such as metal-to-metal contact at the bearings of mill shaft.

The Use of a Permanent Magnet: In the mill redesign, use could be made of a very powerful permanent magnet installed inside the spout of the mill machine to be able to attract the filings from the ground food flour. This magnet must retain the iron filings after attracting them to itself. Secondly, it should be easy to mount into and detach from the spout and this calls for flexibility of magnet material.

REDESIGN CONCEPTS OF GRINDING MILL

Redesign concepts of grinding mill depend upon the following apparatus:

The Misalignment Detecting Sensor and Signaling Apparatus: The sensor and signaling apparatus helps to maintain the minimum space between the grinding surfaces without touching in times of finest grind of food material.

Block Diagram of Sensor and Signaling Apparatus: The assembly of the rotating grinding plate and the drive shaft make up the rotor, and the stationary grinding plate together with the housing and the frame and other stationary components of the mill make up the stator.

With reference to the redesigned mill diagram, a rotary machine, with the rotating part, the rotor, and the stationary part, the stator, and an acoustic sensor is installed on one of the bearings supporting the drive shaft S of the rotor. The acoustic sensor is connected at its output terminal to a detector circuit 26 through an amplifier circuit 25. The detector circuit 26 is connected at its output terminal to a rubbing detection circuit 27 which includes a variable band-pass filter circuit 29 and a rectifier circuit 31a. The detector 26 is connected also to an abnormal metal-to-metal contact detection circuit 28 which includes a low-frequency band-pass filter circuit 33, a rectifier circuit 31b and a comparator circuit 34. The comparator 34 outputs the contact display signal.

A rotational speed sensor provides an output signal synchronous with the rotation of or having a frequency proportional to the rotational speed of the rotor and is connected at its output terminal to the variable band-pass filter circuit 29 in the rubbing detection circuit 27 to apply a control input signal to the filter circuit 29. The rectifier circuit 31a in the rubbing detection circuit 27 is connected at its output terminal to the comparator circuit 34 in the abnormal metal-to-metal contact detection circuit 28 and also to a rubbing display monitor 32. The rectifier circuit 31b in the abnormal metal-to-metal contact detection circuit 28 is connected at its output terminal to an abnormal metal-to-metal contact monitor 35 through the comparator circuit 34.

Rubbing Condition Detection and Monitoring: Suppose, for example, that an out of axial alignment condition is present between the central axis of the drive shaft S of the rotor and that of the bearing. Then, an acoustic signal generated due to the out of axial alignment condition between the central axis of the drive shaft S of the rotor and that of the bearing is transmitted via the bearing material to the acoustic sensor (see fig. 5). Suppose, on the other hand, that rubbing occurs at a point R (see fig. 6) between the rotor (rotating part) and the stator.

Although the rotor and the stator are shown out of contact with each other so as to clearly distinguish the rotor from the stator, it would be assumed that the rotor and the stator are actually in contact with each other at this point R, resulting in occurrence of rubbing at the point R. Then, an acoustic signal generated due to the rubbing contact between the rotor and the stator propagates through the rotor as shown by the line P to be transmitted to the acoustic sensor via the oil film in the bearing. Consequently, the two acoustic signals, that is, the acoustic signal generated due to the out of axial alignment at the bearing and the acoustic signal generated due to the rubbing contact between the rotor and the stator are simultaneously received by the signal acoustic sensor.

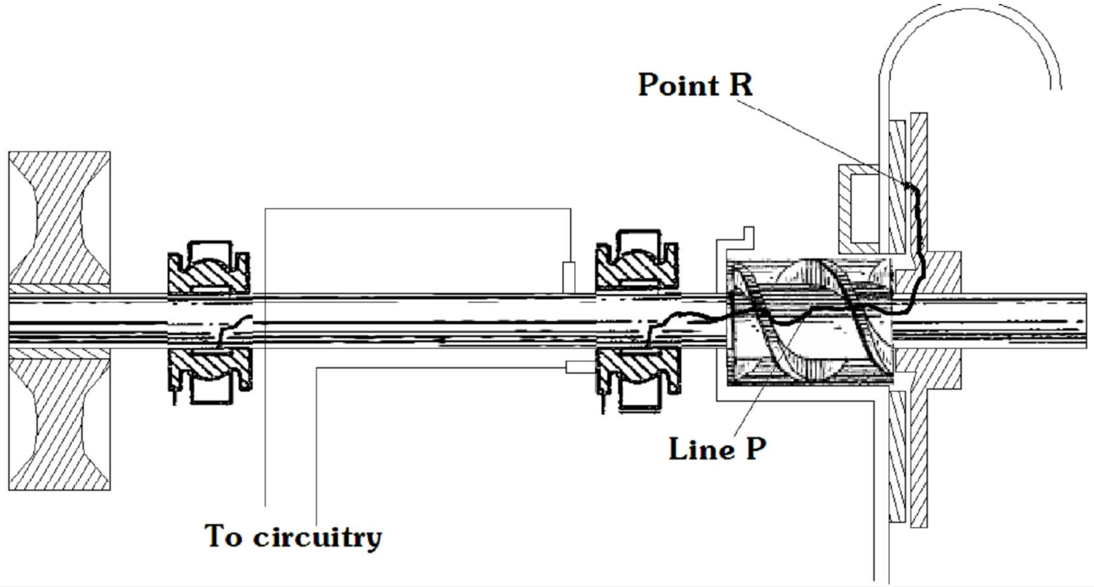

Fig. 5 Redesigned Grinding Mill

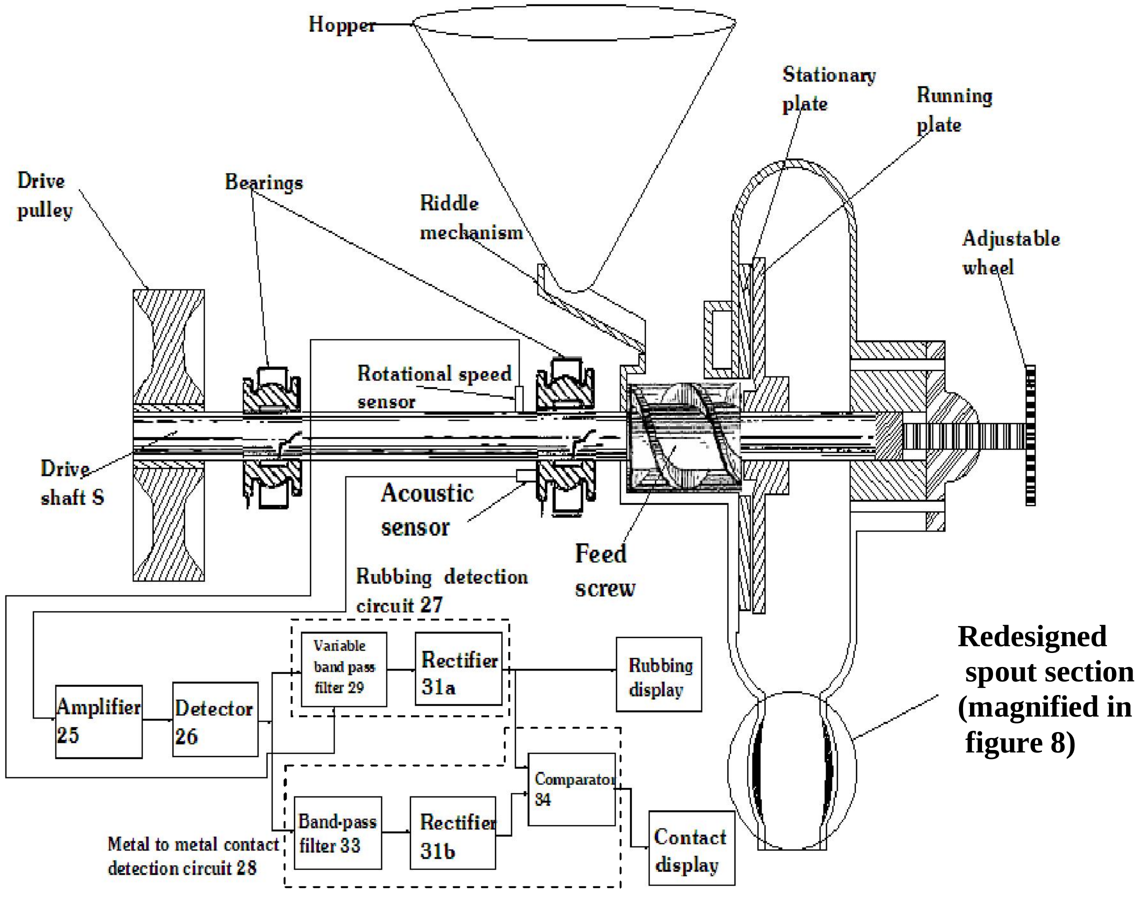

Fig. 6 Rubbing at Point R

The two acoustic signals received by the acoustic sensor are amplified by the amplifier circuit and then detected by the detector circuit. Fig. 7(I) shows the waveform of the output signal from the amplifier circuit, and Fig. 7(II) shows the waveform of the output signal from the detector circuit. The output signal from the detector circuit is applied to the rubbing detection circuit and also to the abnormal metal-to-metal contact detection circuit. From the detector output signal applied to the variable band-pass filter circuit in the rubbing detection circuit, the rotational frequency component tuned to the rotational frequency of the rotor is only detected under control of the control signal applied to the filter circuit from the rotational speed sensor. The output signal from the filter circuit is applied to the rectifier circuit to be converted into an averaged voltage signal which is applied to the rubbing monitor.

Thus, the output signal from the variable band-pass filter circuit 29 has a waveform tuned to the rotational frequency of the rotor (Fig. 7(III)). The signal waveform is rectified by the rectifier circuit 31a into the signal waveform depicted in Fig. 7(IV). In the event of the occurrence of rubbing, the amplitude signal density (ASD) becomes higher in the rotational frequency pass band described and the level of the output voltage from the rectifier circuit 31a becomes higher. Therefore, by monitoring the voltage signal applied from the rectifier circuit 31a to the rubbing monitor 32, occurrence of rubbing can be detected as soon as it occurs. Due to the fact that the output signal from the rectifier circuit 31a includes only the signal component tuned to the rotational frequency of the rotor, rubbing can be monitored without being affected by the background noise.

Abnormal Metal-to-Metal Contact Detection: On the other hand, in the abnormal metal-to-metal contact detection circuit 28, the output signal of detector 26 is applied to the low-frequency band-pass filter circuit 33, and, after conversion into an averaged voltage signal in the rectifier circuit 31b, it is applied to the comparator circuit 34 where it is compared with the voltage signal applied from the rectifier circuit 31a of the rubbing detection circuit 27. The resultant output signal of comparison is applied to the abnormal metal-to-metal contact 35.

Thus, the output signal from the band-pass filter circuit 33 has a waveform including various low-frequency components (Fig. 7(V)) and the output signal from the rectifier circuit 31b rectifying the output signal from the band-pass filter circuit 33 has an averaged voltage level (Fig. 7(VI)). The voltage signal from the rectifier circuit 31b includes the rubbing signal component described above. Therefore, this output signal from the rectifier circuit 31b is applied to the comparator circuit 34 to be compared with the output signal from the rectifier circuit 31a, so that the output signal from the comparator circuit 34 provides an averaged voltage level representative of the average of the signal components other than the rotational frequency component (Fig. 7(VII)).

In the event of occurrence of abnormal metal-to-metal contact between the drive shaft S of the rotor and the bearing, the amplitude signal density (ASD) becomes higher throughout the entire frequency range, and the level of the output voltage from the comparator circuit 34 becomes higher (Fig. 7(VII)). Therefore, by monitoring the output voltage signal of the comparator circuit 34 at the abnormal metal-to-metal contact monitor 35, the occurrence of abnormal metal-to-metal contact at the bearing can be reliably detected as soon as it occurs using a high sensitivity acoustic sensor. When the output signal from the detector circuit 26 is passed through the low-frequency band-pass filter circuit 33 before being applied to the rectifier circuit 31b, the signal applied from the comparator circuit 34 to the monitor 35 does not include any high-frequency noise.

In the table 2, H = High output voltage level, L = Low output voltage level

Conclusively, a summary of the state of operation at any given time in terms of the presence or absence of trouble could be given by way of voltage signals of the independent monitors 32 and 35 and hence clearly identify the specific situation.

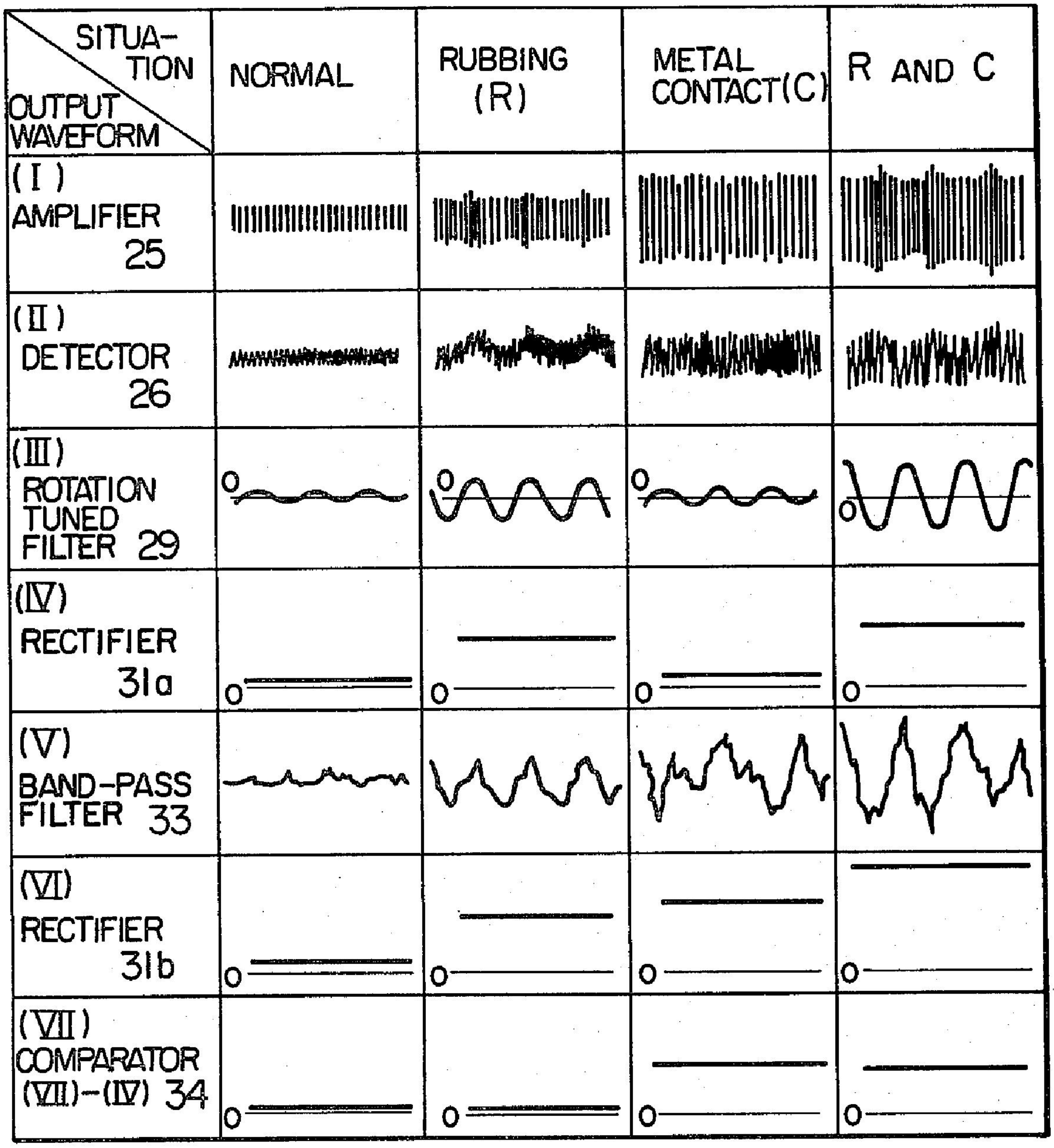

Fig. 7: Waveforms of Output Signals.

Table 2: The Output Signals of the Rectifier Circuit and Comparator Rectifier Circuit

	Trouble-Free	Occurrence of Rubbing (R)	Occurrence of Metal- to-Metal Contact (M)	Simultaneous Occurrence of R and M
Rectifier circuit 31a (Fig. 7 (IV))	L	H	L	H
Comparator circuit 34 (Fig. 7 (VII))	L	L	H	H

Rubbing and Contact Displays: In their simplest practical form, the monitors 32 and 35 may be voltmeters or voltage recorders, and their indications may be read to readily identify the specific situation. In another form, the voltage signals applied from the circuits 31a and 34 by way of the two routes may be processed by a logic circuit. The effect may be similar when the acoustic sensor is mounted on, for example, the casing (the pedestal) supporting the bearing. The use of this apparatus is further advantageous in that the capability of detection of the occurrence of abnormal metal-to-metal contact and the occurrence of rubbing by the same apparatus facilitates maintenance and greatly economizes the costs.

Incorporation of a Flexible Ring Permanent Magnet: It is important that the magnet is flexible, permanent and of ring structure. With these features if offers ease of mounting and removal due to the flexibility and retention of the attracted iron filings due to the permanent magnetism (an electromagnet will loose its filings when the magnetizing influence is removed) and the creation of a good column of magnetism for the effective attraction of the filings due to the ring structure.

Modalities of Design of a Flexible Ring Permanent Magnet: The design need be such that the cylindrical length of the ring magnet would be long enough to make sure most of the filings are attracted before they finally get out of the region of the magnetic field. Also, the magnet would be affixed in a cavity along the spout of the grinding mill so that the attracted filings would not be detached by friction from the movement of the ground material coming out of the spout. Spout temperature must not affect the magnet in terms of demagnetization. After several grinding operations the mill is stopped for a short period of time and the attracted filings are cleaned off the curved cavity.

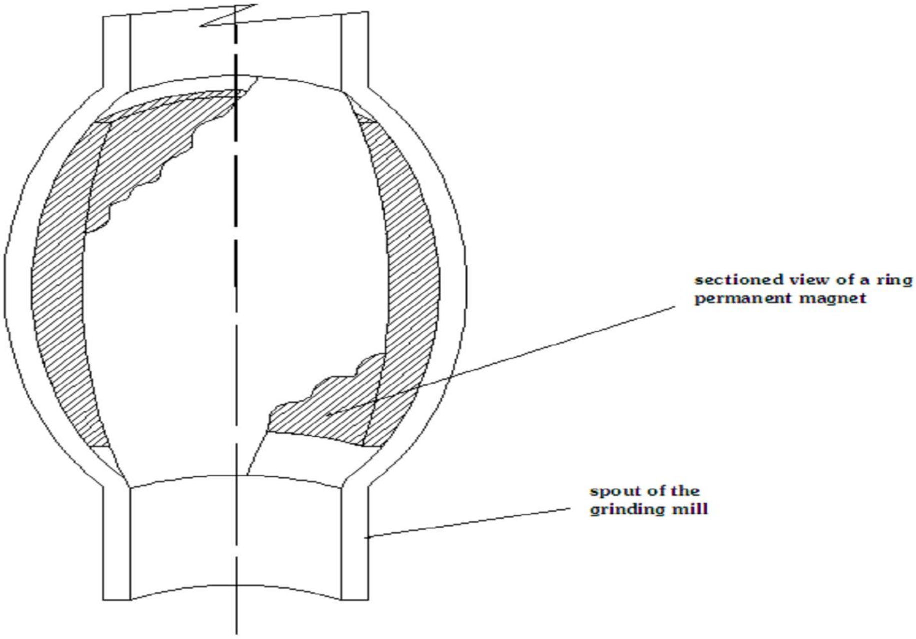

Fig.8: Magnified View of the Permanent Magnet

Modern Permanent Magnet Materials and Design Considerations: An effective choice of magnet material must ensure its availability and suitability. Issues of suitability start with the hysteresis curve for permanent magnet materials.

Modern permanent magnet materials: There are four classes of modern commercialized permanent magnets, each based on their material composition. Within each class is a family of grades with their own magnetic properties.

These general classes are:

- Neodymium Iron Boron, NdFeB
- Samarium Cobalt, SmCo
- Ceramic magnet
- Alnico

NdFeB and SmCo are collectively known as rare earth magnets because they are both composed of materials from the Rare Earth group of elements. Neodymium Iron Boron is the most recent commercial addition to the family of modern magnet materials. At room temperatures, NdFeB magnets exhibit the highest properties of all magnet materials. Samarium cobalt is manufactured in two compositions: Sm_1Co_5 and Sm_2Co_{17}. The Sm_2Co_{17} type with higher H_{ci} values, offer greater inherent stability than the Sm_1Co_5 type.

The B-H curve: The basis of magnet design is the B-H curve, or hysteresis loop, which characterizes each magnet material. This curve describes the cycling of a magnet in a closed circuit as it is brought to saturation, demagnetized, saturated in the opposite direction, and then demagnetized again under the influence of an external magnetic field.

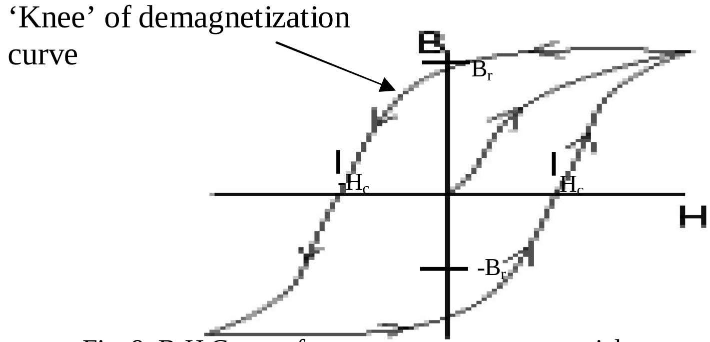

Fig. 9: B-H Curve of a permanent magnet material

where, B_r = Residual magnetic flux density, H_c = Coercive force, BH_{max} = Maximum energy product

The second quadrant of the B-H curve, commonly referred to as the "demagnetization curve", describes the conditions under which permanent magnets are used in practice.

Design considerations: B_r represents the maximum flux the magnet is able to produce under closed circuit conditions. In actual useful operation, permanent magnets can only approach this point. Br is remanent magnetism; the higher it is, the higher the magnetic flux retained in the absence of an external magnetic field of strength H ($B=B_r$ at $H=0$). Hc represents the point at which the permanent magnet becomes “demagnetized” under the influence of an externally applied magnetic field. The higher the coercive force Hc, the more difficult it will be to demagnetize the magnetic material. BHmax represents the point at which the energy density of the magnetic field is at a maximum. The higher this product, the smaller need be the volume of the magnet and also the larger the amount of energy needed for demagnetization of the permanent magnet. The total flux density of the permanent magnet is composed of two components given by

$$B = \mu H + B_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where,

μ = Permeability of the permanent magnet material
H = Applied external magnetic field
B_i = Intrinsic magnetic flux density of permanent magnet material.

In normal operating conditions, no external magnetizing field is present, and the permanent magnet operates in the second quadrant, that is the demagnetization curve region. Although strictly negative, H is usually referred to as a positive number, hence in normal practice the intrinsic magnetic flux density is given by the formula,

$$B_i = \mu H + B \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

It is then possible to plot an intrinsic as well as a normal B-H curve. The point at which the intrinsic curve crosses the H-axis is the intrinsic coercive force denoted by H_{ci}. High Hci values are indicative of inherent stability of the permanent magnet material. The normal curve can be derived from the intrinsic curve and vice versa. In practice, if a permanent magnet is operated in a static manner with no external magnetic fields present, the normal curve is sufficient for design purposes. The design must also account for the variation of the B-H curve with temperature. The higher the maximum practical operating temperature and the curie temperature of permanent magnet material, the more the reliability. The basic problems of permanent magnet design revolve around estimating the distribution of magnetic flux in a magnetic circuit.

A table of permanent magnet material comparisons gives a broad but practical overview of factors that must be considered in selecting the proper magnet material, grade, shape and size of magnet for a specific application.

Table 3: Comparison of Permanent Magnet Materials

Material	**Grade**	**B_r (T)**	**H_c (kA/m)**	**H_{ci} (kA/m)**	**BH_{max} (kJ/m^3)**	**T_{max} (Deg C)***
NdFeB	39H	1.28	979	1671	160-360	150
SmCo	26	1.05	732	796	160	300
NdFeB	B1ON	0.68	460	820	10	150
Alnico	5	1.25	51	51	13.5	540
Ceramic	8	0.39	255	259	3.5	300
Flexible	1	0.16	109	110	0.6	100

(Extracted from: Anon, 2000 at http://www.magnetsales.com/Design/DesignG_htm)

Permanent Magnet Stability: Stability can be described as the repeated magnetic performance of a material under specific conditions over the life of the magnet. The ability of a permanent magnet to support an external magnetic field results from small magnetic domains "locked" in position by crystal anisotropy within the magnet material. Once established by initial magnetization, these positions are held until acted upon by forces exceeding those that lock the domains. The energy required to disturb the magnetic field produced by a magnet varies for each type of material. Permanent magnets can be produced with extremely high coercive forces (H_c) that will maintain domain alignment in the presence of high external magnetic fields.

Factors affecting magnet stability include time, temperature, reluctance changes and shock, stress, and vibration.

Table 4: Effects of Certain Factors on Permanent Magnets

Factor **Magnet**	**Time(Flux loss for 100,000 hrs at low P_c)**	**Temperature**	**Magnetic Reluctance Changes**	**Shock, Stress and Vibration**
NdFeB	Nil due to high Hc	Highly reversible but irreversible and unrecoverable losses could be high beyond T_{max}	Unchanged if air gap dimensions remain constant during operation	Minor below destructive limits
SmCo	Nil due to high Hc	Reversible and could experience irrecoverable losses	Unchanged if air gap dimensions remain constant during operation	Minor below destructive limits but could be great above limits as it is fragile! Thermal shock could cause fractures

Alnico	Less than 3% especially for Alnico 5 due to the very low Hc	Quite reversible. Very Stable at higher temperatures	Unchanged if air gap dimensions remain constant during operation	Minor below destructive limits
Ceramic	Less that 3% due to low Hc	Uneasy reversibility. Irrecoverable losses are hardly experienced	Unchanged if air gap dimensions remain constant during operation	Can develop fractures due to thermal shock when exposed to high temperature gradients

Modern permanent magnets see changes known as “magnetic creep” immediately after magnetization due to less stable domains being affected by fluctuations in thermal or magnetic energy, even in a thermally stable environment. However, rare earth NdFeB and SmCo do not experience this effect because of their extremely high coercivities. Secondly, magnetic reluctance changes cause the magnet’s operating point to fall below the ‘knee’ of the demagnetization curve, causing partial and or irreversible losses. Stabilization could be achieved by pre-exposure of the magnet to the expected magnetic reluctance changes. Shock, stress and vibration effects are minor below the destructive limits. However, brittleness and rigidity of magnet material is crucial to the survival of shock, stress and vibration.

*The effects of temperature***:** These are threefold. Firstly, the reversible losses. They are recovered when the permanent magnet returns to its original temperature. Reversible losses cannot be eliminated by magnet stabilization. Secondly, there are irreversible but recoverable losses. They are partial demagnetization of the magnet form exposure to high or low temperatures. Recoverability is actualised by remagnetisation and not a return to original temperature value. These losses occur when the operating point of the magnet falls below the ‘knee’ of the demagnetisation curve. Thirdly, there are the irreversible and unrecoverable losses due to occurrence of metallurgical changes in permanent magnets exposed to very high critical temperatures and are not recoverable by remagnetisation. Alnico and SmCo having higher critical temperatures are not likely to suffer from these losses.

Table 5: Reversible and Critical Temperature Coefficients of Modern Permanent Magnets

Temp. ºC / **Material**	**Reversible, %/ºC T_c of B_r**	**Reversible, %/ºC T_c of H_c**	**Critical Temp. ºC T_{curie}**	**Critical Temp. ºC T_{max}**
NdFeB	- 0.12	- 0.6	310	150
SmCo	- 0.04	- 0.3	750	300
Alnico	- 0.02	0.01	860	540
Ceramic	- 0.2	0.3	460	300

Partially demagnetizing a magnet by exposure to elevated temperatures in a controlled manner stabilizes the magnet with respect to temperature. The slight reduction in flux density improves a magnet’s stability because domains with low commitment to orientation are the first to lose their orientation. A magnet thus stabilised will exhibit constant flux when exposed to equivalent or lesser temperatures.

NUMERICAL ANALYSIS AND RESULTS

Permanent Magnet Calculations: Calculation of permanent magnet parameters is threefold:

- Determination of magnet length, pole area and permeance coefficient.
- Calculation of flux density.
- Magnetic field force calculations

- *Determination of magnet length L_m, pole area A_m and permeance coefficient P_c*: In the absence of any coil excitation, the magnet length and pole area may be determined by the following equations:

$$L_m = \frac{B_g L_G}{H_m} \quad (5)$$

$$A_m = \frac{B_g A_g}{B_m} \quad (6)$$

Where:

B_m = Flux density at the operating point,
H_m = Magnetizing force at the operating point,
A_g = Air-gap area,
L_g = Air-gap length,
B_g = Gap flux density,
A_m = Magnet pole area,
L_m = Magnet length.

Combining the two equations, the permeance coefficient P_c may be determined as follows:

$$P_c = \frac{B_m}{H_m} = \frac{A_g L_m}{A_m L_g} \quad (7)$$

$$\text{Strictly}, \; P_c = \frac{B_m}{H_m} = \mu\left(\frac{A_g L_m}{A_m L_g}\right)k \quad (8)$$

where,

μ = The permeability of the medium
k = A factor which takes account of leakage and reluctance that are functions of the geometry and composition of the magnetic circuit.

The objective of a good magnet design is usually to minimize the required volume of magnet material by operating the magnet at BH_{max}. The permeance coefficient at which BH_{max} occurs is given in material properties tables.

Consider that a particular field is required in a given air-gap, so that the parameters B_g, H_g (air-gap magnetizing force), A_g, and L_g are known. Applying equation (7) and table 3, it can be concluded that rare earth materials offer reasonable to high values of flux density at very high values of magnetizing force. Consequently, very short magnet lengths are needed, and the required volume of magnet material will be small. However, again from table 3, the maximum operating temperature of NdFeB is far less than that for SmCo. This leaves SmCo as the authentic choice provided it can pass the flexibility test.

- *Calculation of flux density on a magnet's central line for ring shaped magnet:* For magnet materials with straight-line normal demagnetization curves such as rare earths and ceramics, it is possible to calculate with reasonable accuracy the flux density at a distance X from the pole surface (where X>0) on the magnet's centerline under a variety of conditions.

$$B_x = \frac{B_r}{2}\left(\left(\left(\frac{L+x}{\sqrt{R^2+(L+x)^2}}\right)-\left(\frac{L+x}{\sqrt{r^2+(L+r)^2}}\right)\right)-\left(\left(\frac{x}{\sqrt{R^2+x^2}}\right)-\left(\frac{x}{\sqrt{r^2+x^2}}\right)\right)\right) \text{........(9)}$$

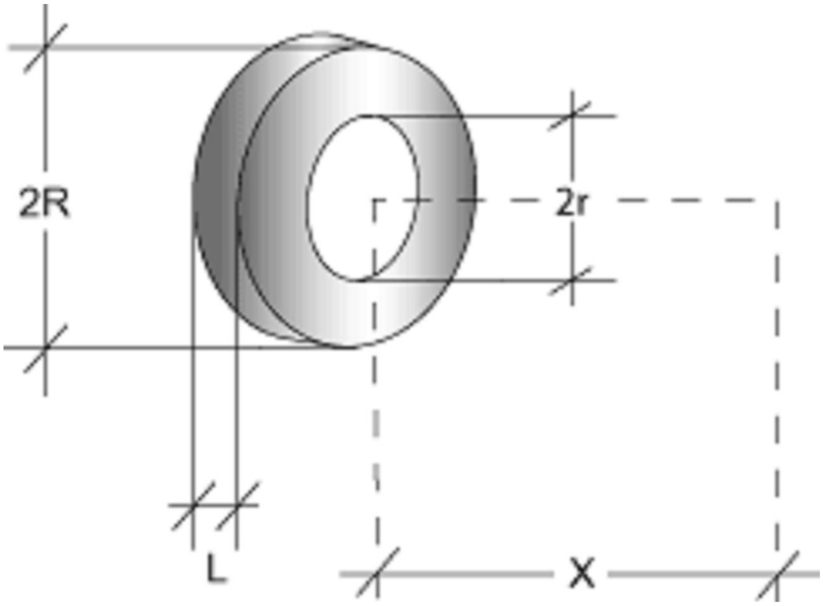

Fig.10: Calculation of the Magnetic Flux Density of a Ring-Shaped Magnet

- *Magnetic field force calculations:* The attractive force exerted by a magnet on a ferromagnetic material could be calculated by the formula:

$$F = 0.577\, B^2 A \text{ ………………………………………......(10)}$$

where,

F = Force
B = Flux density in Kilotesla
A = Pole area in square meters.

Approximate holding force for rare earth and the ceramic magnets (magnet exhibiting straight line demagnetization curve) is given by the formula. (Source:http://www.magnetsales.com/Design/DesignG_htm)

$$F \approx 0.58 B_r L_m \sqrt{A} \text{ …………………………………….(11)}$$

where,

B_r = Residual flux density of the material
A = Pole area in square meters
L_m = Magnetic length in meters kept within the bounds of normal, standard magnet configurations.

Assembly Considerations: Magnet assembly design options include affixing magnet to housing using adhesives, redesign of housing for effective location of magnet, mechanical fastening where the magnet is encased, pinned or strapped with non-magnetic metal components, laser welding and so on. The best option for the application to grinding mills is redesign of housing and the permanent magnet material of choice samarium cobalt Sm_2Co_{17} must be manufactured in flexible form. Consideration of the special flexible ceramic magnet means costly tradeoffs due to its comparatively far inferior values of BH_{max}, H_c, B_r, H_{ci} and T_{max} (Table 3).

CONCLUSION

The grinding mill plays a major role as far as food processing is concerned in the local communities. The findings have made it quite clear the harm that we invite onto ourselves. Unintentionally, we have imbibed iron filings as part of our daily diet.Use of the grinding mill to grind grains and other foodstuffs produced iron filings as part of the food consumed giving rise to iron overload or hemochromatosis which is the cause of a myriad of health disorders. A redesign of the grinding mill was effected using sensors, misalignment detecting mechanism and a permanent magnet device. The rare earth modern magnetic material Samarium Cobalt (SmCo) was selected to drastically minimize occurrence of iron filings in the grounded food material.

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