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21' x 32'   L/D ~ 1.5

SYDVARANGERS 6.5 M DIAMETER x 9.65 M BALL MILL

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SUMMARY

The Sydvaranger ball mill is the largest in the world grinding iron ore. The design is in addition unconventional as the mill shell is equipped with riding rings placed upon pad bearings and driven by a 8.1 mW wrap around motor. The background for the decision to install the mill is given together with design and construction considerations. Operational experience after 5 years and 20 mill tons of ore is discussed.

INTRODUCTION

A/S Sydvarangers at Kirkenes has produced magnetic concentrate from a low grade taconite orebody since 1910. As the plant was totally destroyed during the second world war, the major part of concentrator buildings date from 1953. Since then plant capacity has gradually been increased to a maximum of 5.8 million tons in 1984 and a pellet plant has been added.

A general flowsheet of the concentrator after fine crushing is given in figure 1. The ore is ground in two stage ball mills both in closed circuit and with a succeeding magnetic separation stage. A final upgrading is done by reverse flotation (ref.1). Roughly 50 % of the feed is rejected after the first stage grinding/magnetic separation as a tailing containing 0.2 - 0.5 % magnetic iron. Unliberated gangue follows the magnetic concentrate to the next grinding stage. Final concentrate holds about 69.5 % Fe.

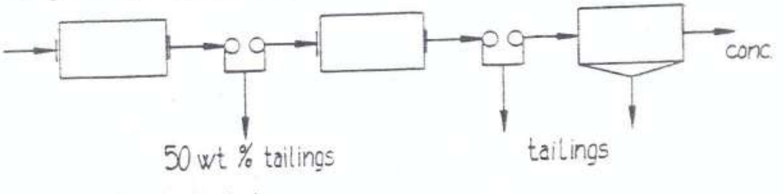

Fig. 1. General flowsheet Sydvaranger

As production was increased and harder and leaner ore was expected, comminution capacity had to be increased. The following three options were considered:

1) Close and enlarge fine crushing circuit
2) Introduce rod milling

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3) Install more ball milling capacity

Alternative 1 was found extremely costly as the crushing plant partly is placed excavated in hardrock.

Alternative 2 would also be costly as it required considerable building extensions as rod mills need extensive charging equipment etc. Both alternatives would probably require a plant shut down.

Introduction of more ball milling capacity in the shape of a single large ball mill that replaced one smaller, was much cheaper, if existing silo and feeding equipment could be used with minor modifications.

The large mill alternative was chosen and has now operated for more than 5 years. As this mill represent an evolution in mill design it is time to review the construction and operation of the mill.

FLOWSHEET CONSIDERATIONS

Economics dictated that the new mill had to fit into the space left after the original 900 kW mill and its classifier shown in figure 2.

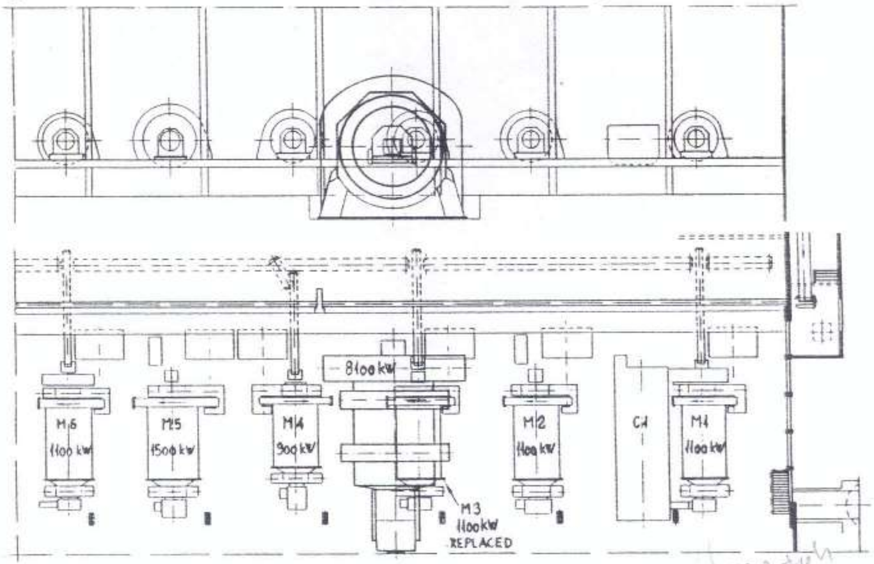

Fig. 2. The new mill placed in the existing grinding bay.

The mill centerline height could not be changed too much if existing feed and pulp systems should be utilized. Foundation and erection work would be very close to the operating mills.

Classification and closed circuit operation was a problem to be considered. There was no room for a screw classifier which was the traditional primary classifying method at Kirkenes. Cycloning with large circulating loads was expected to give pumping and wear problems because of large, hard and heavy particles.

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The idea that a primary large diameter mill would give enough internal classification was conceived, not at least because the original Kirkenes mills operated in open circuit.

A classification effect could be obtained by running the mill with a freeboard above the ball charge. The pulp pool will be quieter the larger the mill is, hence better classification. How large this pool had to be was not known and required ball filling and power was an uncertain point.

Some material to coarse for the pulp handling system would be discharged anyway. The mill had therefore to be equipped with a 2.0 m diameter x 3.5 m long trunnion screen from which +2.5 mm oversize was screwed back into the mill. This screen was not meant to replace a classifier, failure of internal classification would lead to screen overloading and tons of gravel at the floor.

DESIGN AND MANUFACTURE

Background

The design of mills for mineral dressing has basically been unchanged for a long period of time in spite of the fact that mills have grown larger and larger. This has resulted in structural and mechanical problems, causing expensive failures and loss of production. Sydvaranger was therefore pleased to learn that Scanmec had new and interesting ideas for how large mills should be designed and manufactured. The problems of large mills are well known but ought to be summarized:

1) Mill heads and trunnions are carrying high loads.

2) The structural load distribution of the mill barrel is unsound.

3) Ring gear transmissions have power limitations, and are vulnerable to misalignments causing unexpected wear and breakages of vital mill parts. They are also vulnerable to high and unexpected wear caused by lubrication problems. The transmission has usually an unacceptable noise level.

4)The designs of trunnion bearings and in and outlet openings are in conflict. a) Trunnion bearings are close to feed and discharge material, which often have resulted in bearing failure or oil seal problems.

b) Trunnion liners have to be long and narrow which give difficult transport and wear problems.

c) The construction is very expensive for large mills.

5) Mill and drive foundations have to take up a very complex load distribution.

6) Motors and transmissions occupy much valuable floor space.

7) Startups result in peak loads on the power net.

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The new design

The design shown in figure 3 combines elements of proven new technology in one large mill.

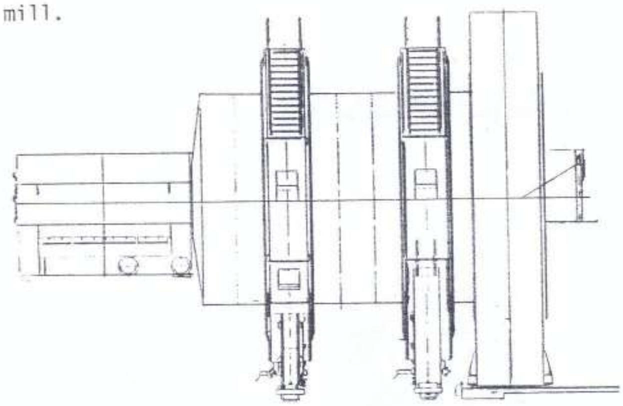

Fig. 3. The Sydvaranger 8.1 mW mill

A) Wrap around motors have been successfully used for many years in the cement industry (ref.2 and 3). The problems of power transmission are eliminated. Mill speed can be varied from inching speed to max. r.p.m. The start up period is fully controlled, which results in a moderate load on the power net. It was necessary to redesign the existing ring motor type to fit the mill concept. The motor housing was placed on bedplates at the same level as the mill shell bearings. This design allowed a new internal motor cooling system, which eliminated external cooling air channels, which otherwise would require nonexistent space. Much attention was made to convert the motor to suit a wet grinding mill. The resulting motor which includes a converter-thyristor configuration has a total of 56 field poles and a supply frequency of 6.1 Hz at rated speed. Motor efficiency, which in this case is total motor and transmission efficiency, is near 95 %, and is nearly independent of mill speed and load. The air gap between stator and rotor is 13 mm and a tolerance of ±1.5 mm was required by the motor manufacturer (ref.4).

B) Large pad bearings were acknowledged (ref.5) and used together with riding rings mounted on the mill shell. This leaves the mill heads to a great extent unloaded. Trunnion bearings are thereby eliminated, so in and outlet openings can be designed to suit their principal function.

Adjustable pad bearings for the 8.5 m diameter riding rings are developed to support the mill shell safely and rigid.

The pads have an advanced and special designed adjustment system making it possible to adjust the motor gap precisely and timesaving. The adjustment system also allow for accurately sharing of pad loadings.

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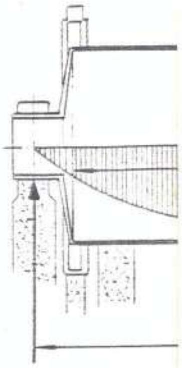

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have in addition high pressure oil supply before and during starting periods.

Special attention was taken to find a leak proof and dust tight type of oil seals for the bearings, and so far there has been no oil leakages at all.

The seals installed originally are still in service, and are expected to last for years.

B2) The pad bearings can be placed to optimize the shell stress distribution. The stresspeaks are remarkably reduced (fig. 4). Particularly are the critical heads and head to shell joint stresses reduced significantly.

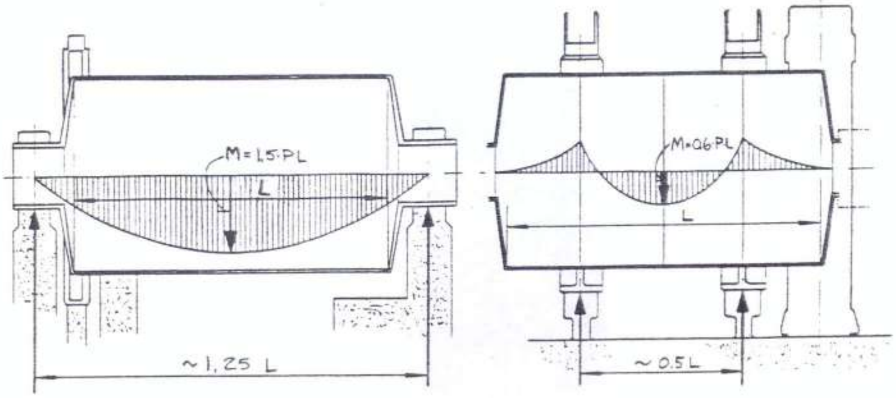

Fig. 4. Stress distribution in conventional and new mill design

Mill shell integrated with heads without trunnions can all be fabricated. Due to the ellimination of cast heads the manufacturing process has been changed to fabrication only.

C) The technique for splitting large mill shells into smaller parts for shipment and assembly at the site of erection was well developed and most of the ring motors had also been delivered in splitted design. It was essential that the parts could be handled by the existing overhead cranes.

TABLE 1: Technical specifications

Mill diameter outside liner	6500 mm	
inside liner	6140 mm	DI
Mill length outside liner	9650 mm	
inside liner	9100 mm	
Bearing diameter	8500 mm	
Feed end opening diameter	1150 mm	
Discharge inside diameter	1980 mm	DF
Trunnion screen diameter	2000 mm	
Trunnion screen length	3500 mm	
Motor power	8.1 mW	

RH = 0,339

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Mill speed	2.5 - 13.1 rpm
Critical speed	17 rpm
Max mill feed	1000 t/h
Ball filling	22 - 30 %, 300 - 450 t
Max design ball filling	45 %, 635 t

Mill manufacture and assembly on site

As the mill is designed for complete fabricated manufacture, the workshop had to be capable of rolling and bending heavy steel plates, and also be experienced in welding and heattreating such materials. The machining of the mill shell flanges was carried out in the welding shop by a special portable machining tool with high grade of accuracy. All other parts were machined in regular machining shops.

The mill erection was planned in detail at the time it was designed because both size and weights on many parts were on the border of what could possibly be handled in the mill building. By two paralell overhead cranes, the big items, the largest weighed 67 tons were transported across the bay with rotating mills. Some had to be turned 90 degrees hanging in the cranes to make assembly possible.

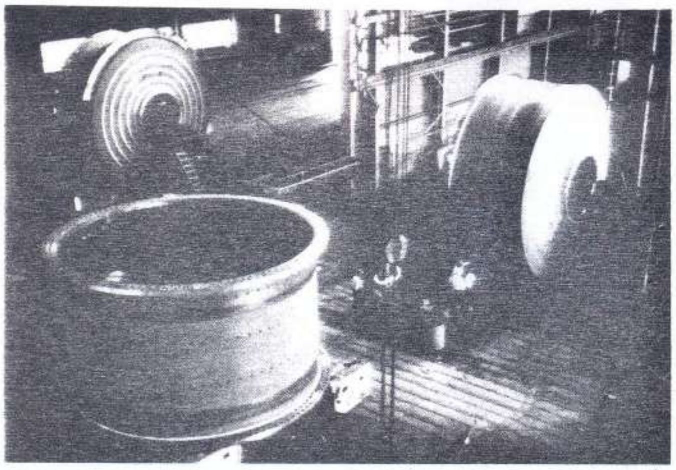

Fig. 5. Machining of shell

Figure 6

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Figure 6 demonstrates the space problem during transportation.

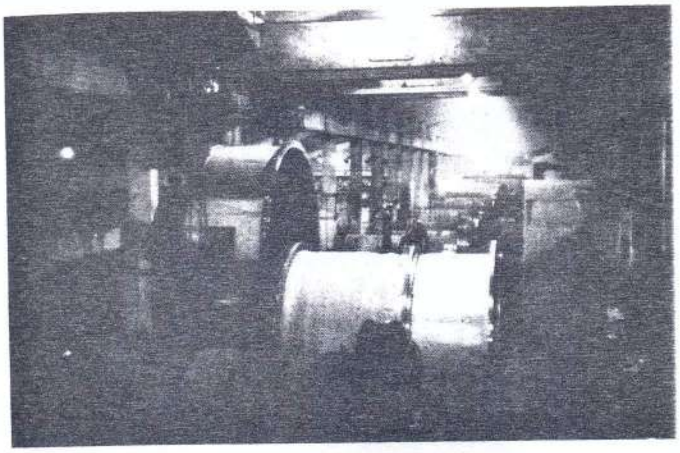
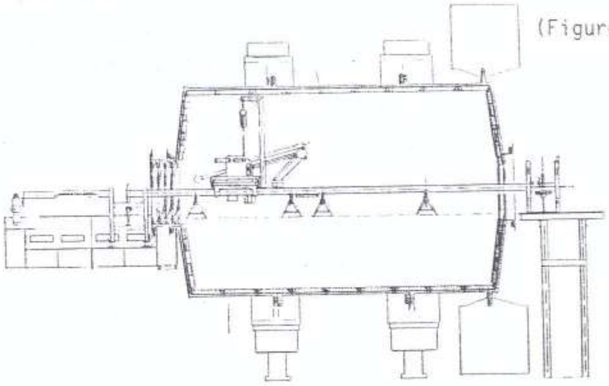


Fig. 6. Transport of mill shell

Mechanical change of mill liners

As the liner parts would be made from steel castings having good magnetic permeability, all handling inside and outside the mill should be carried out by electromagnets. The magnets are operated mechanically to bring the liner parts in correct angular position on shell or heads, and an air operated manipulator is used to carry the weights of parts and magnets. The only manual work left is to hold the liner up against the shell or head surface and to insert the liner bolts. The handling machine is travelling on a steel beam inserted into the mill through the feed and discharge openings. Figure 7 as well as a wagon to transport new and worn liners.



(Figure 7)

Fig. 7. Mechanical liner handling machine

The mill can be rotated at inching speed with the equipment installed even when the ball charge is at a maximum level.

The system has been successfully used from the first change of liner parts.

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PROCESS CONTROL

The objective of the control is to get as many tons through the mill as possible. A large amount of gangue is easily liberated and about 50 % of the feed is discharged as tailing after the first separation stage. Grinding fineness is therefore less important as long as the feed can be handled without problems in pumps and separators. The trunnion screens remove stray oversize but do not act as a classifier. That does not mean that one gradually may increase mill feed and gradually get a coarser product as a result. At one point the mill charge swells and the mill quits grinding. This may follow a too high feed rate, coarser or harder feed or water problems. Pilot testwork in laboratory scale as well as testwork in one original mill at Kirkenes demonstrated this problem clearly. The testwork showed also that operators faced with those problems operated wisely with a safe low feed. The alternative might have been to shovel gravel for a week.

It was therefore essential that a process control system could give an early warning of an overfill situation.

Power consumption is always a good indicator for the state of a primary mill If the power drops there is a fair chance of overfill. This warning may be too late to take any action however.

Autogenous mill experience is that mill weight is a good indicator of the state in the mill. An increase may indicate that critical size particles (particles too large to be crushed by the grinding media) build up within the mill. Pilot testwork demonstrated, contrary to common belief, that a fair measurement of the ore content in a ball mill can be obtained by weighing the entire mill. The maximum change in charge weight may be up to 10 % of the total charge weight. Specific gravity changes of the ore will give similar effects but usually much smaller.

The testwork was done too late to design the mill support structure to include strain gauges. Instead the oil pressure of one of the pad bearings was accurately monitored. This does not give an exact charge weight but a good indication of weight status when the oil has reached a constant temperature.

Mill weight gave an earlier warning of charge buildup than mill power and operators following both could obtain an increased throughput. Occasional overruns did still occur and a trial was done to monitor discharge particle size by an Autometrics Analyzer. This project had to be abandoned as coarse particles too frequently plugged the sample pipes.

Controlled variables are mill speed and the usual feedrate and water supply.

Monitoring of mill data over a long time showed that the relation between controlled variables and measurements of power and mill weight are complex. A model and for this relationship has been developed (ref.6) and also a PC simulator which can be used for operator training.

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The operators relied on one more parameter, however. It was found that the loading of the trunnion screen is a good indication of the size distribution of the mill. This is in fact included in the above model, but not as an observed parameter. The screen is 3.5 m long and ideally 50 % of the capacity should be utilized. Utilization of more screen area indicates that the mill product and charge is getting courser and some action has to be taken. The state of the screen is now available to the operator in the control room on a TV monitor. The signal could possibly be changed into a measured variable on the computerized data gathering system as the other mill variables shown in figure 8.

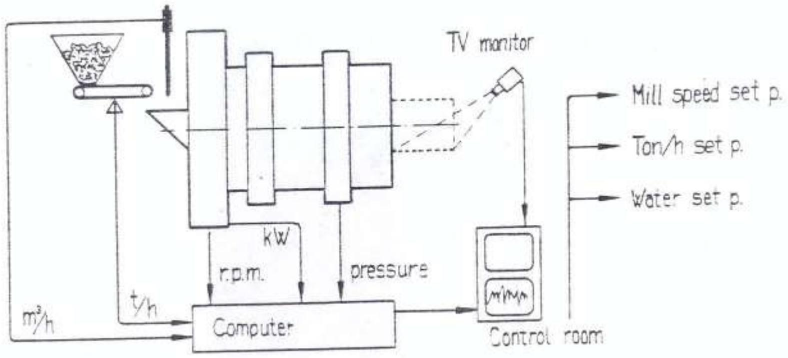

Fig. 8. Data gathering system for the 8.1 mW mill

OPERATIONAL RESULTS

Statistics

Since startup in 1981 a total of 20 million tons have been milled. Throughput has varied between 500 and 1050 t/h depending principally upon ore hardness, but also upon points on a learning curve. From 1983 to 1986 the average throughput has increased from 567 t/h to 617 t/h while energy consumption has been lowered from 10.5 kWh/t to 7.91 kWh/t. Ore hardness may have been about unchanged as power consumption of the remaining small mills have increased from 8.8 to 10.2 kWh/t. A more detailed statistics is given in tables 2 a and b.

TABLE 2: Production statistics

a)	New mill	others
Product fineness, wt % less than 208 µm	82.4	80.0
Ball consumption, g/kWh 1986	82.6	74.3
Liner consumption, g/kWh 1986	5.6	6.5
Liner consumption, g/t 1986	44.0	66.0

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b)

1986	t/h Large mill	t/h others	kWh/t Large mill	kWh/t others	Balls, g/t Large mill	Balls, g/t others	Hardness factor	Libe-ration
1	599	97	7.43	10.77	793	734	2.51	72.6
2	566	99	8.74	10.06	704	795	2.50	72.1
3	643	100	8.14	9.92	651	877	2.41	74.3
4	596	86	7.52	10.34	535	852	2.43	76.7
5	568	88	8.63	10.53	514	345	2.55	74.6
6	627	89	7.72	9.41	764	917	2.40	76.6
9	608	90	6.30	10.30	738	672	2.43	74.1
10	609	84	9.03	10.97	567	770	2.49	72.5
11	651	90	8.63	9.92	895	1446	2.36	74.9
12	663	-	7.87	-	460	-	2.37	75.1
Σ	617	90	7.90	10.22	653	759	2.43	74.5

Falta: Energía do Classificador, maior consumo de agua, bombas, etc

From table 2 a) it can be seen that the large mill consumes more balls in grams per gross kWh to the mill motor than the smaller ones. It is reasonable to expect that the ball consumption per net kWh is equal for two mills grinding the same ore to approximately the same fineness. If this is done, ball wear gives an estimate of electrical/mechanical efficiency and the calculation on this basis shows that the large mill is 10 % better. The large mill consumed totally 22 % less energy per ton milled, the remaining 12 % may be attributed to more efficient grinding.

Mill operation

The concept of operating a large open circuit primary mill was new to everybody involved and it had to be learned. Pilot work had shown that overfilling of the mill could occur, so it came as no surprise when it did.

Control strategy was not enough, first the internal classification system had to function. One started originally with a full mill 40 % charge level. The internal classifying action was then poor and the outside trommel screen was overloaded when the mill operated with a reasonable feed. The charge was then gradually reduced to 22 % and the internal classification worked. The discharge size distribution is now more or less the same as the overflow from the classifiers of the smaller primary mills.

This reduction in ball loading did not decrease grinding capacity as the extra power supplied with the larger size was wasted on overgrinding.

The reduction in ball charge has also resulted in lower grinding media consumption. Ball size was reduced from a maximum of 125 mm to 115 mm with no

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effect on grinding during 1986. Pulp density is kept as high as possible, 65 - 68 % solids by weight or 34 - 38 % by volume to reduce ball consumption. The mill speed is generally kept constant at 12.1 rpm, 71 % of critical. It is mainly raised by the operators when the hardness of the ore increases to avoid overfilling.

Design data versus operational results

The mill was the first of its kind and the internal classification feature made calculation of throughput and power consumption difficult.

The motor was therefore dimensioned for the maximum power the mill could possibly draw and maximum throughput was then calculated from the known kWh/t for the primary mills. This resulted in a motor size of 8.1 mW and a feed capacity of 1000 t/h.

The reduction in ball level to improve internal classification reduced average mill power to 4.87 mW for 1986 at a production of 617 t/h. This is close to what may be calculated using conventional mill formulas. It may therefore appear that the safety factor applied have been on the high side. However, power peaks at 7 mW of one hour duration has been observed, as a result of ore accumulation in the charge. This may happen because of the large freeboard.

As a conclusion it can be said that mill capacity has been lower than anticipated. Other design criteria such as lower kWh/t ground, lower grinding media consumption and maintenance requirement have been met.

Operational surprises

After approx. 1 year of operation the liner on the outlet mill head started to crack. Different reasons were suggested: Mill head was too flexible, fastening system too stiff, wrong type of material in liners/balls, etc. There had been a change to a harder type of balls, and at one time the ball change had been drastically increased only with large balls. After changing back to the original ball type, and regularly supplying balls, the problem disappeared. The mill head was prepared with holes for another liner fastening system, but this was not taken into use.

Direct startup of the full mill is possible because the motor gives full torque at a low speed. The pulp settles fast and cements the volumetric small ball charge. At one inspection a lateral mill movement of 25 mm was discovered. It took some time to find the reason. The whole charge did not fluidize when the mill was started but stuck with the liner to a high position before it thundered down. The damage possible to mill and motor wrappings when 300 tons of steel drops 6 m may be imagined. The mill proved to be though enough to take this handling, but automated start up procedures were introduced to prevent reoccurences.

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DISCUSSION

Construction

The major reason why the Scanmec-Sydvaranger design is superior to conventional design for large mills is economical. From a certain size this construction is cheaper to make and it moves upwards the size of mills that can be made (ref. 7).

The wrap around motor gives the following advantages:

- Limited startup currents. Stepless speed variation.
- Simple power transmission. Noise- and maintenance-free.
- Increased energy efficiency.
- Reduced floor space requirement.

The pad bearing system gives:

- Ideal support of mill body.
- Ideal feed and discharge openings.
- Reduced downtime and spare part consumption.
- Simplified manufacture.

Combination of the above factors and splitting of the mill in smaller parts for local assembly makes the design ideal for:

- Plant rehabilitation.
- Tailor making.

Operation

The mill has been operated at high and low ball charges. It has been shown that successful coarse grinding in open circuit requires a large pool of pulp above the grinding charge for classification. This is easy to obtain by the new design. For fine grinding, for what the mill has not been tested, a high ball load and cyclone classification should probably be recommended.

It has also been demonstrated that ball mill weight and trunnion screen loadings can be useful tools for mill control. Mill speed variation is used routinely for grinding power control.

For coarse grinding it is most important however, that the new mill is using less power per ton than the older ones with classifiers and that the past years of successful operation at Sydvaranger has given lower operational and maintenance cost.

REFERENCES

1 K.L. Sandvik and B.A. Dybdahl, Upgrading of taconite concentrate to direct reduction specifications by flotation, 52nd anual meeting of the Minnesota section of AIME and the 40th annual mining symposium Jan. 1979, Daluth Minnesota.

2 D.A. Fenton et al., Operation of the 8750 hp gearless ball mill at St. Lawrence Cement, Society of mining engineers meeting, Oct. 1977.

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3 K. Isch, A. Ablinger and H. Wolf, Study reviews world's gearless mill drives, Zement-Kalk-Gips, August 1977.

4 W. Meintrup and P. Klein, World's largest ore grinder without gears, Society of mining engineers annual meeting, Feb. 1982.

5 D.D. Fuller, Theory and Practice of Lubrication for Engineers, Wiley 1984.

6 K.L. Sandvik, Lenhartzen, A charge weight based mill model, Ist World Congress of Particle Technology, Nürnberg 1986

7 B. Försund and B. Torgersen, Die größte getriebelose Kugelmühle der Welt, Betriebserfahrungen von A/S Sydvaranger bei Kirkenes in Norwegen, Verein Deutscher Ingenieure, Arbeitssitzung Zerkleinern März 1987.