BEHR'S STAGE WINDING SYSTEM - AN ALTERNATIVE SOLUTION FOR HOISTING FROM 4000 M

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SYNOPSIS

For more than 100 years Gold mining in South Africa has been characterised by the great depths at which ore extraction takes place. To make the access and operations as efficient and economic as possible shafts of up to 3200 m are currently being sunk for single lift hoisting and shafts with depths of 4000 m are planned for the near future. In such deep installations the suspended mass of rope becomes very significant and can well exceed the mass of men, material or rock which are being transported. In order to reduce the physical size and power requirements of the winding plant for 4000 m it is necessary to consider alternative hoisting systems to conventional double drum winders, one of these is the Stage winder first proposed by Behr in 1902. In such a system, a second conveyance is suspended below the main conveyance on a double drum winder with a suitable payload changeover system at approximately mid-shaft. This paper demonstrates how the system could be applied successfully to a 4000 m deep installation through implementation of existing technology. A "tapered mass" solution is readily achieved by using a Blair multi-rope winder with two ropes in the upper section of the shaft and one in the lower. The key technical parameters of the winding plants which would be required for 100 000 tonnes/month through to 250 000 tonnes/month capacity shafts have been calculated. The main advantages of this solution compared to full single lift hoisting from 4000 m are shown to include : lower out of balance mass at the extreme positions of the wind, likely reductions in capital costs, the same length of rope on the drum as for a 2000 m deep shaft and fairly significant reductions in drive power requirements.

Keywords :

deep shaft mine hoisting, Blair Multi-Rope winders, Stage winding, alternative hoisting technology.

1 INTRODUCTION

It is nowadays generally accepted that the development and installation of winding plant for single lift shafts down to 4000 m is inevitable for efficient access to future South African gold reserves. Over the last 10 to 15 years there have been numerous investigations into the feasibility of such systems, trying to quantify the design requirements and likely equipment specifications. Greenway[1] developed model drum winder duty cycles for depths ranging from 3000 m to 4000 m while modifying key design parameters away from standard practice. Through this parametric study, realistic depths of wind and hoisting capacities were established and it was concluded that 4000 m in a single lift is achievable using current rope and drum winder based technology.

In connection with the study of Greenway, Sparg[2] considered in more detail Blair multi-rope (BMR) winder design specifications specifically for a 4000 m installation with 8.5 m diameter drums, two 64 mm ropes per drum and conveyance payloads of 18.3 tonnes. The application of BMR winders to very deep shafts was also examined critically by Girodo and Sparg[3] . These examples of work reported to date indicate the feasibility of achieving realistic production capacities from great depth but it is recognised by most authors that wire rope technology may be the main factor affecting the successful application of the 4000 m winding systems. The development of deep level rope technology is a special field which is dealt with in other papers presented at this conference.

Although drum winding with high tensile steel wire ropes is likely to be the preferred option for 4000 m, other technologies are being considered. Linear synchronous motors to replace rope based drum winders have been proposed by Cruise and Landy[4]. The objective in this case is to remove shaft depth as a key parameter affecting the suitability of the hoisting technology, an issue which has also been highlighted by Wainwright[5] in connection with the future challenges for deep level vertical transport.

It is the topic of this paper to report an investigation into the comparison of BMR winders for 4000 m with an alternative solution, not as radical as linear synchronous motors, but one based on the BMR design with an additional conveyance suspended in each shaft compartment, the Behr Stage winder. Behr[6] first proposed the concept of Stage winding in 1902. Figure 1 shows a comparison of the configuration of the BMR winder with the Stage winder. More recently Stewart[7] has re-examined the Stage system in the context of ultra deep vertical shafts. Stewart found in principle that a significant advantage can be obtained by using Stage winding at depths of 4000 m or more. The maximum feasible rock production of 140 000 tonnes per month from 4000 m was regarded as a limiting factor in the application of such a system. However, Stewart's calculations were based on limitations of the rope capacity factor value at the conveyance end which no longer needs to apply to new winding system designs, under certain conditions.

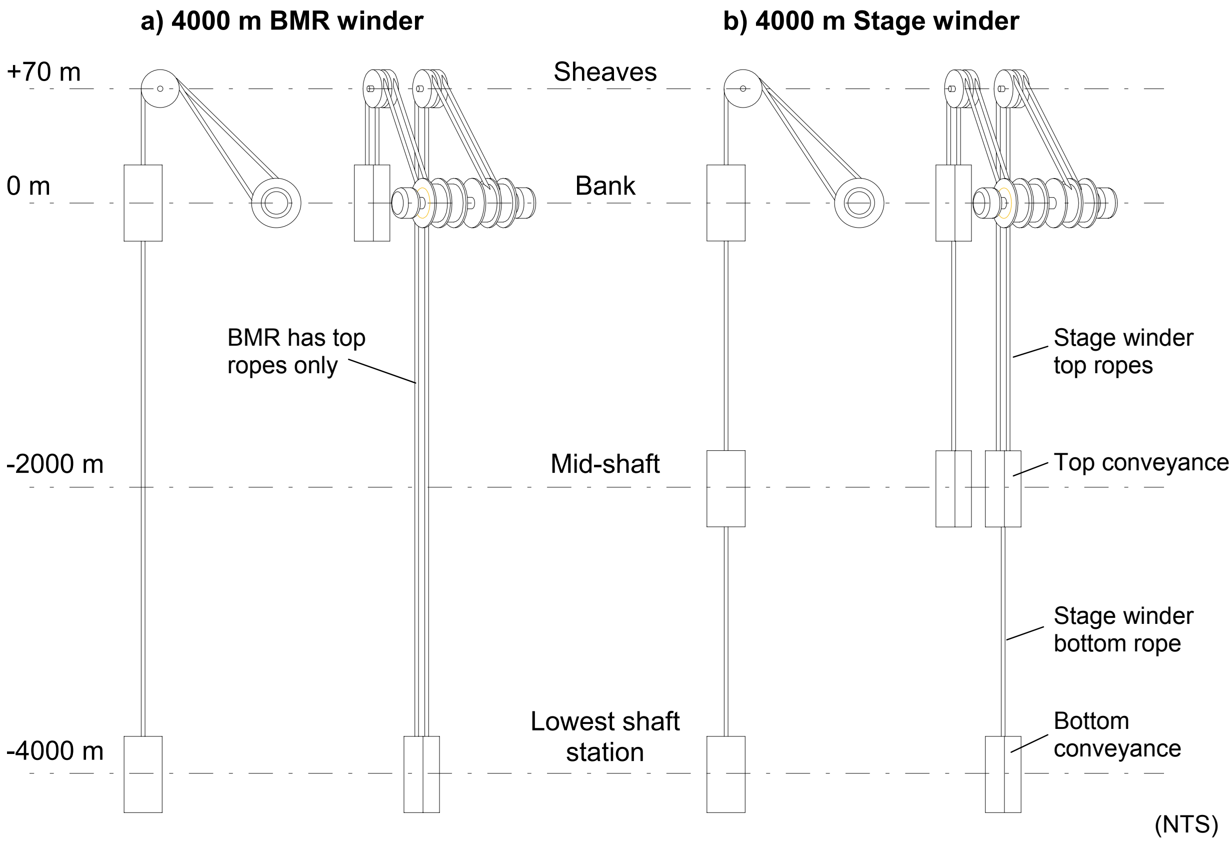


Figure 1 - General elevations of (a) the Blair multi-rope winder and (b) the Behr Stage winder for servicing 4000 m deep shafts.

The comparative technical calculations for this present investigation were based on a range of rock production capacities from 100 000 to 250 000 tonnes per month (in steps of 25 000 tonnes). In each case matching BMR and Stage man winders were also specified. Section 2 of the paper describes in detail the proposed system parameters, operation and design assumptions and in Section 3 the results of the calculations for all 28 winding systems (7 rock capacities, four winders types for each) are compared. The term Stage winding should not be confused in any way with winding arrangements which are commonly used for sinking shafts.

2 WINDING SYSTEM DESCRIPTIONS AND CALCULATION ASSUMPTIONS

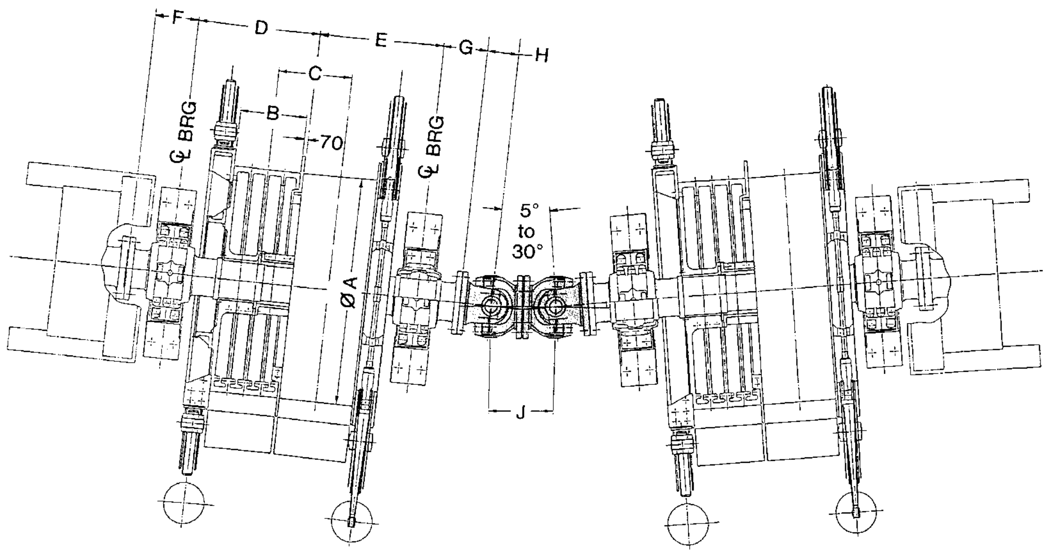
With reference to Figure 1, it can be seen that the maximum suspended top rope lengths are 4070 m for the BMR and 2070 m for the Stage winder. In the case of the Stage winder the bottom rope suspended length is 2000 m ignoring the size of the conveyances. Maximum winding distances are as follows :

Stage rock	= 2050 m
Stage man	= 2000 m
BMR rock	= 4050 m
BMR man	= 4000 m

The total top rope length was determined from the maximum suspended length, a catenary of 100 m and an allowance of 15 dead turns on the drum at installation with the conveyance at the lowest position in the shaft (L + 100 m + 15 dead turns).

2.1 Winder drums and motors

Both the BMR winders and Stage winders are assumed to have the same winding plant configuration on surface as shown in Figure 2. Each drum has two rope compartments and the two drums are mounted on a common shaft (one drum being clutched to the drum shaft for operational adjustments to the relative positions of the conveyances). Depending on the drum compartment widths, the distance between the winders and the shaft and the resulting angle which the winding ropes make with the headgear sheaves, the drums may need to be inclined inwards using a Hook's joint (such installations are currently being used in South Africa to overcome fleeting angle problems).



ØA	B	C	D	E	F	G	H	J
5140	1900	1970	3450	3250	1100	1100	710	1420
5540	2200	2270	3875	3825	1200	1200	760	1520
6540	2000	2070	3725	3675	1300	1300	860	1720
6040	2200	2270	3975	3875	1300	1300	860	1720

Figure 2 - General arrangement of an inclined BMR winder, using a universal coupling linkage (Hooks joint) between the drums. Typical drum dimensions are shown, adapted from Sparg[2].

The winder drive motors are directly coupled to the winder shaft and have overhung rotors, also shown in Figure 2. For the RMS rating calculations it was assumed that the motors are cooled by forced ventilation.

For the calculations, drum and sheave to top rope diameter (D:d) ratios of 120:1 for the Stage winders and 140:1 for the BMR winders were used. The latest SABS code of practice for drum winders[8] recommends a minimum D:d at 19 m/s of 116:1 and a maximum for all rope speeds of 140:1.

Drum compartment widths were adjusted in the calculations (0.1 m increments) such that for the required winding rope diameter and drum diameter the maximum number of rope layers were 4 for the Stage winders and 5 for the BMR winders. A rope pitch of 1.055 x d was used which is also in accordance with SABS 0294[8].

2.2 Winder utilisation and underground manpower requirements

Knowing the winding distances for the four types of winders being considered, winder running times per trip were determined taking into account realistic acceleration and creep values :

Stage rock, 19 m/s, 2050 m

Assumed 0.9 m/s^2 acceleration and deceleration, no creep out, 5 s creep in at 0.5 m/s $\therefore$ cycle time = 133.9 s

Stage man, 19 m/s, 2000 m

Assumed 0.9 m/s^2 acceleration and deceleration, 15 s creep in and out at 0.5 m/s $\therefore$ cycle time = 140.1 s

BMR rock, 19 m/s, 4050 m

Assumed 0.5 m/s^2 acceleration and deceleration, no creep out, 5 s creep in at 0.5 m/s $\therefore$ cycle time = 256.2 s

BMR man, 19 m/s, 4000 m

Assumed 0.5 m/s^2 acceleration and deceleration, 15 s creep in and out at 0.5 m/s $\therefore$ cycle time = 276.9 s

Rock and man loading times of 10 s and 180 s respectively were assumed. The maximum number of rock trips per month was then calculated based on 26 days of operation and 75 % utilisation per day. With the shaft capacity specified (tonnes per month) the payload to be hoisted per trip was then easily determined.

For the shaft underground manpower requirement it was assumed that the mining productivity would be 40 tonnes per month per man and that 80 % of these people would be on day shift, all needing to be transported down to the 4000 m working level in one and a half hours. These assumptions lead to the calculation of the man cage capacities (No. of men). An allowance of 75 kg per man was used in determining man payloads.

2.3 Skip and cage factors and rope factors of safety

Bottom skip and cage factors (empty conveyance / payload) including attachments was taken as 0.7 and 1.0 for the Stage rock and Stage man winders respectively. For the top skip and cage factors, including attachments, the following values were used :

Stage rock	1.1
Stage man	1.6
BMR rock	0.7
BMR man	1.0

The circa 60% increase in factor going from the bottom conveyances on the Stage winders to the top is due to the increase in load carrying capacity required from the bridle of the top conveyance. They need to support their own payload as well as the bottom rope, bottom conveyance and its payload. All of these skip and cage factors are not unrealistic judging from current designs, if anything they are on the conservative side.

In accordance with Regulation 16.34.2 of the Mine Health and Safety Act[8] the minimum allowed top and bottom rope selection factors (static factors of safety) were determined from the equation : 25000/(4000+L) where L is the maximum suspended rope length (top or bottom).

2.4 Inertia of moving components and shaft friction

Due to the number of cases considered (28 winders) it was not feasible to independently calculate the exact inertia of each drum and sheave. Seven accurate inertia values were obtained from a major South African winder manufacturer. It was assumed that the inertia (kg.m^2) would increase linearly with drum width and by some power of the drum diameter. A curve of this form was placed through the data as shown in Figure 3 and the curve was then subsequently used to determine all intermediate inertia values. Note that the drum width is factored out in the data shown in Figure 3. The final expression for single drum inertia was found to be :

$$1422.1 * D_{drum}^{3.5795} * W_{drum\_comp} \qquad (\text{kg.m}^2)$$

with both D_{drum} and W_{drum_comp} in metres. The above equation also takes into account the drum shaft inertia.

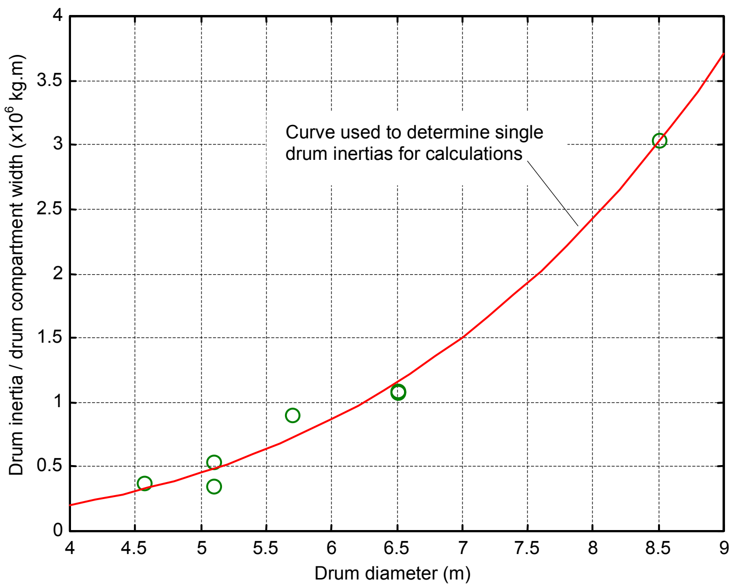


Figure 3 - Examples of real single drum inertia values (factored out by drum width) and the curve used in determining BMR and Stage winder drum inertias for the calculations.

A large South African manufacturer of winder head sheaves was consulted on the inertia per single head sheave and the following equation was recommended :

$$112 * D_{sheave}^{3.2} \qquad (\mathrm{kg.m^2})$$

where the sheave diameter, D_{sheave}, is in metres.

Shaft friction allowance was taken as 10 % of the total payload (in one conveyance) for the BMR winders and 15 % of the total payload (in top and bottom conveyance) for the Stage winders (more friction as a result of two conveyances).

2.5 Winder ropes

Although it is recognised that there may be problems associated with using Lang's lay triangular strand ropes at suspended lengths of 4000 m, these ropes were selected as the top ropes for both the BMR and Stage winders. In the case of the Stage winder the maximum suspended length is only 2070 m so the triangular strand rope is a good choice. It is not impossible that for the 4000 m BMR winders, ropes of similar strength and mass properties but with adequate torque balance could be found to overcome the torsional instability that the Lang's lay triangular strand construction are prone to.

a)

b)

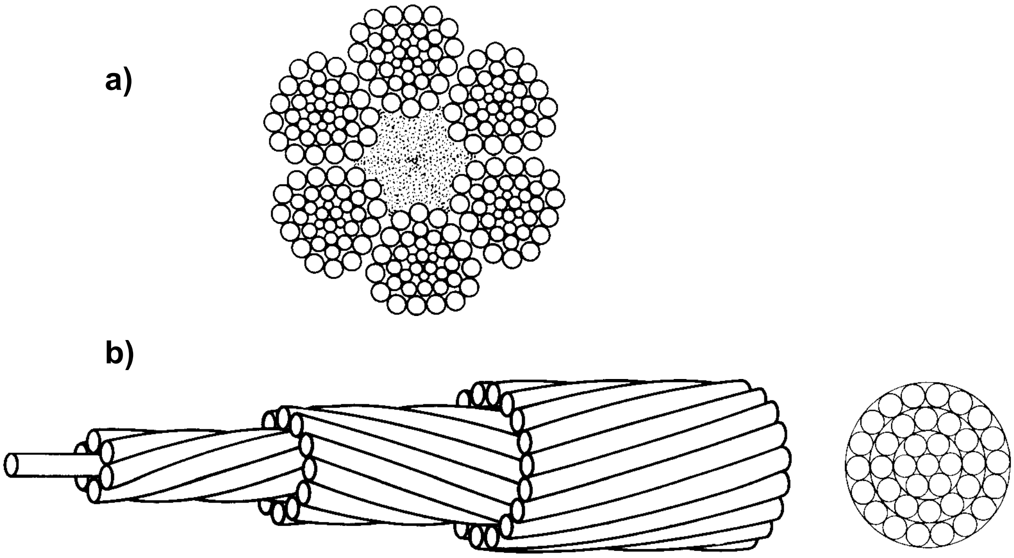


Figure 4 - Stage and BMR winder rope constructions. a) Lang's lay triangular strand ropes used on the BMR winders and top ropes of the Stage winders. b) Torque balanced spiral strand used for bottom ropes of the Stage winders.

The bottom ropes of the Stage winders do not need to operate over sheaves or on to drums, so the spiral strand construction would be suitable there, basically as a long tension member. Spiral strands have good strength to diameter ratios as a result of their compact construction. Close examination of the possibilities for installation of the bottom ropes also highlight that a torque balanced construction is required (a typical property of spiral strands). Figure 4 shows examples of triangular strand rope and spiral strand constructions. The triangular strand ropes are currently by far the most common construction used for drum winding in South Africa.

To simplify the calculation procedure, curves were fitted to the triangular strand rope and spiral strand mass per unit length and diameter versus minimum breaking load (MBL) catalogue values. Figure 5 shows this graphically. This approach allowed the rope MBL to be entered manually such that the required rope selection factor value was achieved. Rope diameter and mass per metre would then automatically be updated (the mass per unit length was in turn used in the safety factor equation).

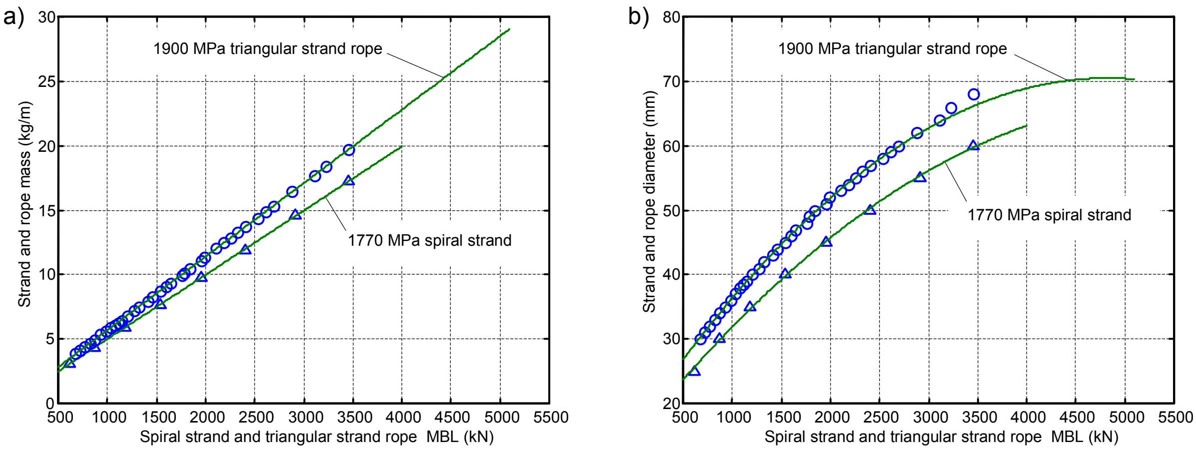


Figure 5 - Variation in spiral strand and triangular strand rope mass per metre (a) and diameter (b) versus the minimum breaking load (MBL). Circles and triangles indicate typical manufacturers' catalogue values, the fitted curve data were used in the winder calculations.

Despite having a lower tensile grade wire (1770 MPa) than the triangular strand rope (1900 MPa), for a given MBL, the spiral strand is on average 12.5 % lighter and has a 11.2 % smaller diameter. This is as a direct result of its more compact construction (refer Figure 4b) and higher efficiency factor.

In connection with decisions on drum diameter to rope diameter ratio, the rope tread pressures on the drum and sheave were calculated (monitored). It is recognised that these should ideally not exceed 3.5 MPa (SABS 0294[8]).

2.6 Stage winder rope length offsets

Figure 6 shows the general arrangement of skips assumed for the Stage rock winders. With one bottom skip at the shaft loading box, the other top skip can be clutched into the headgear tips. This would result in its bottom skip being positioned at the mid-shaft tips 50 m above the adjacent top skip (which would be empty and ready for loading).

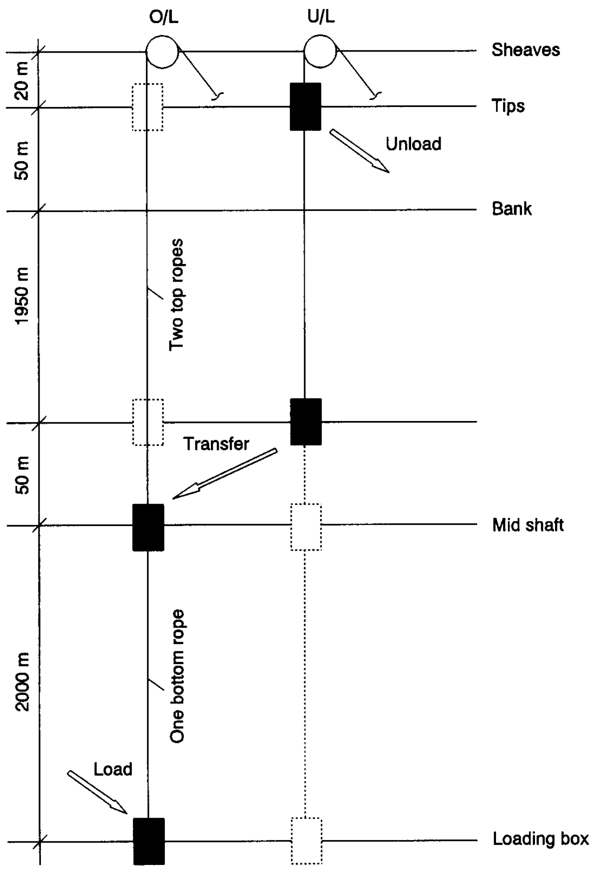


Figure 6 - Rope length configurations allowing for gravity fed mid-shaft transfer of rock in the stage winding system.

2.7 Stage winder mid-shaft transfer arrangements

With the deep shaft rope "problems" essentially solved by splitting the suspended length into two sections, the challenge is really to engineer efficient mid-shaft material and ore handling facilities. It is assumed that hydraulic conveyance holding devices would be required on the top and bottom conveyances.

For man-material systems it may be possible to transfer directly from one conveyance into the other. Alternatively, a turn-around arrangement would probably be more suited to conventional compartment layouts where the conveyance openings usually face the shaft station.

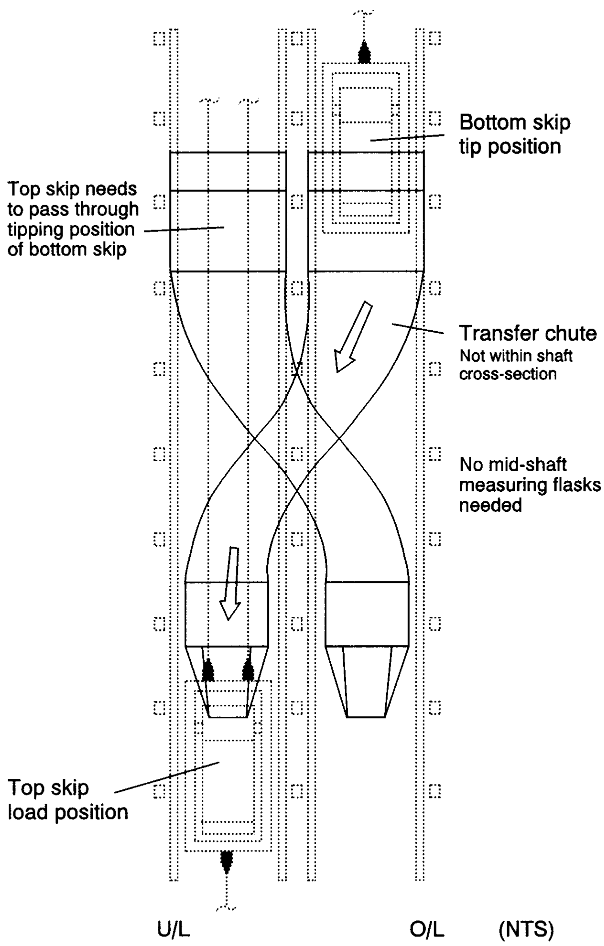


Figure 7 - Possible configuration of the gravity fed mid-shaft rock transfer station (elevation of rock compartments).

In the case of rock winding, if the bottom rope suspended length is shorter than the top rope then the bottom skip would tip above the loading position of the top skip (Figure 6). A small mid shaft ore storage system would enable simple transfer from the bottom skip to the top skip within a compartment. The possibility of tipping one skip directly into the other could also be considered. This would involve a transfer of rock from the bottom skip in one compartment to the top skip in the other compartment thereby eliminating the need for a mid-shaft loading station with measuring flasks etc., as shown in Figure 7.

2.8 Stage winder bottom rope length adjustment

It is most likely that bottom rope degradation will occur more rapidly at the terminations. Occasional re-capping may therefore be required. This would however result in a change in length of the bottom rope affecting the relative positions of the conveyances in the shaft. It is possible that a length of pre-socketed rope could be inserted to replace the cut sections, as shown in Figure 8. This approach would also facilitate cost effective adjustment of the distance between the top and bottom conveyances.

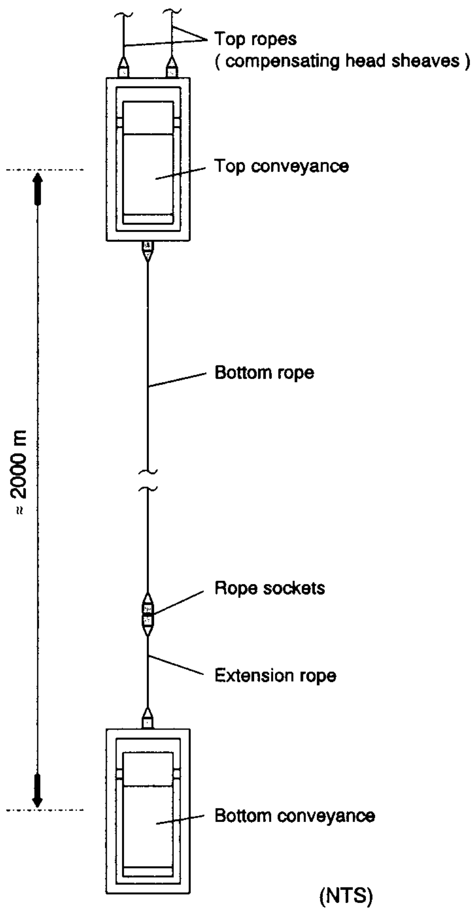


Figure 8 - Adjustment of the overall bottom rope length by inserting an additional pre-socketed rope section. Extension rope probably between 10 m and 30 m in length.

2.9 Stage winder rope installation and maintenance issues

Installation of the top ropes would be as with a conventional BMR winder where all the work is carried out from the bank level. Before the bottom ropes are installed it would be necessary to tension the dead coils on the winder drums.

A mid shaft rope changing level could be created to facilitate installation and maintenance of the bottom ropes and conveyances. During initial installation the BMR winder may be used to lower each bottom rope, on special storage / installation reels, to this rope changing level. These special reels could form part of a rope-changing winch that could be installed on this level. Each bottom conveyance could now be slung below its associated top conveyance and also lowered to the rope changing level where it is spragged in the shaft. The end of the bottom rope would be pulled off the reel and attached to its permanent position on the underside of the top conveyance and pulled up the shaft until it is completely unreeled. Its lower end then being connected to the bottom conveyance, possibly with an extension rope. It is here where good non-spinning characteristics of the bottom rope (strand) is required as one which is not torque balanced would untwist significantly if suspended freely under its own weight for 2000m. Removal of the bottom rope could be done in reverse to the installation.

Maintenance of the top ropes would be exactly the same as on a conventional drum winder. The bottom rope could be inspected magnetically and re-greased as required. Special attention would have to be given to corrosion and to the termination areas. Encapsulating the bottom rope with an extruded PVC sheath is a realistic possibility for corrosion protection as it should not normally come into contact with any other components during operation.

Thought has to be given to replacement of the bottom conveyances from time to time. It is anticipated that this will take place from the mid-shaft position where spare conveyances could be kept.

Shaft inspection and maintenance could be conducted in the normal manner from the winder conveyances, the top half from the top conveyances and the bottom half from the bottom conveyances.

3 WINDER CALCULATION RESULTS

3.1 Winder motor ratings

Detailed technical information and calculation results for each shaft output capacity from 100 000 to 250 000 tonnes per month are contained in the Appendix. The purpose of this section is to show, through a series of composite graphs, how the specifications of the four types of winding plant compare over the range of shaft capacities considered. The first parameter of interest is the required motor ratings (force ventilated RMS and Peak) which are shown in Figure 9.

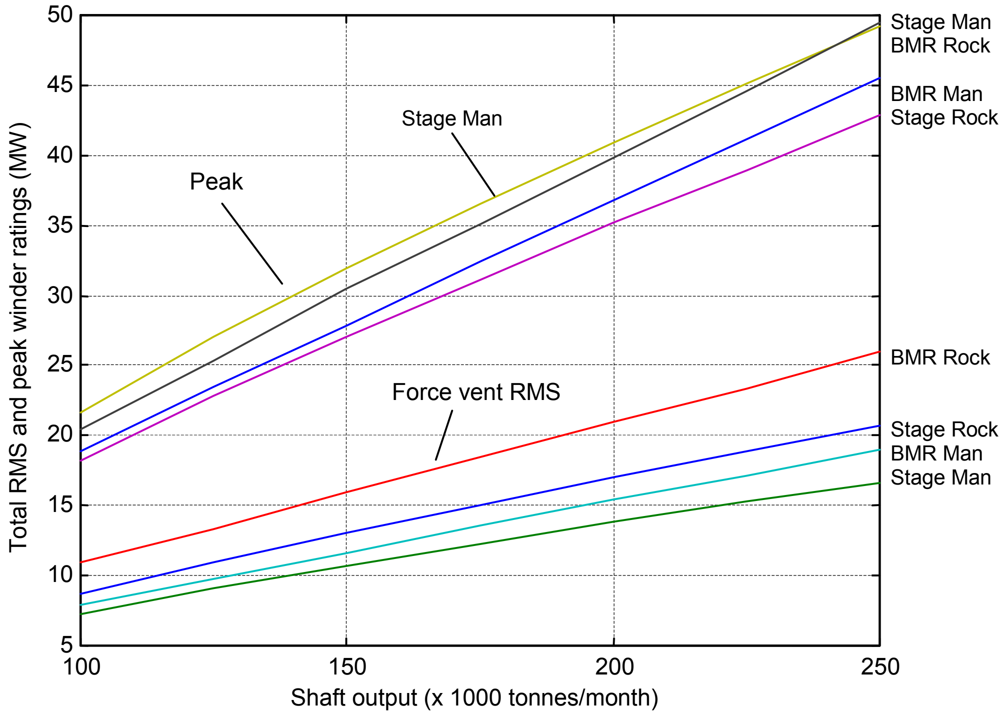


Figure 9 - Calculated total winder motor RMS and Peak ratings for the four types of winding plant considered. Note that the values given are the combined ratings for two motors, the configuration of which was shown in Figure 2.

The average percentage increases in required rating (for all 7 shaft outputs) going from Stage winders to BMR winders are as follows :

Rock RMS : 23.4 %
Man RMS : 10.4 %

Rock Peak : 13.2 %
Man Peak : -11.0 %

A comparison can also be made between the Peak power and force ventilated RMS power for each winding system. The following averages for the seven shaft capacities were found (Peak power / RMS power) :

Stage rock : 2.07
Stage man : 2.97

BMR rock : 1.90
BMR man : 2.40

One of the reasons for the Peak power to RMS ratio being higher for the man winders is that the man winders have a significantly longer standing period for loading. The effect of this is the motors and cyclo-convertors have more "cooling time" and the RMS rating is thus lower. It is no so much a case of the Peak ratings being higher, rather that the RMS figures are lower.

Winder peak kW is highly dependant on the acceleration rate chosen. Lower acceleration rates were chosen for the BMR winders to allow for the extra rounding factors between constant speed and acceleration necessary at these long rope lengths (4070 m).

3.2 Required skip and cage capacities

Figure 10 shows how the rock skip and man cage capacities (collectively referred to as conveyances) increase for the four winding plant with an increase in shaft capacity. Note that the graph has double vertical axes with rock tonnes read off on the left and number of men on the right.

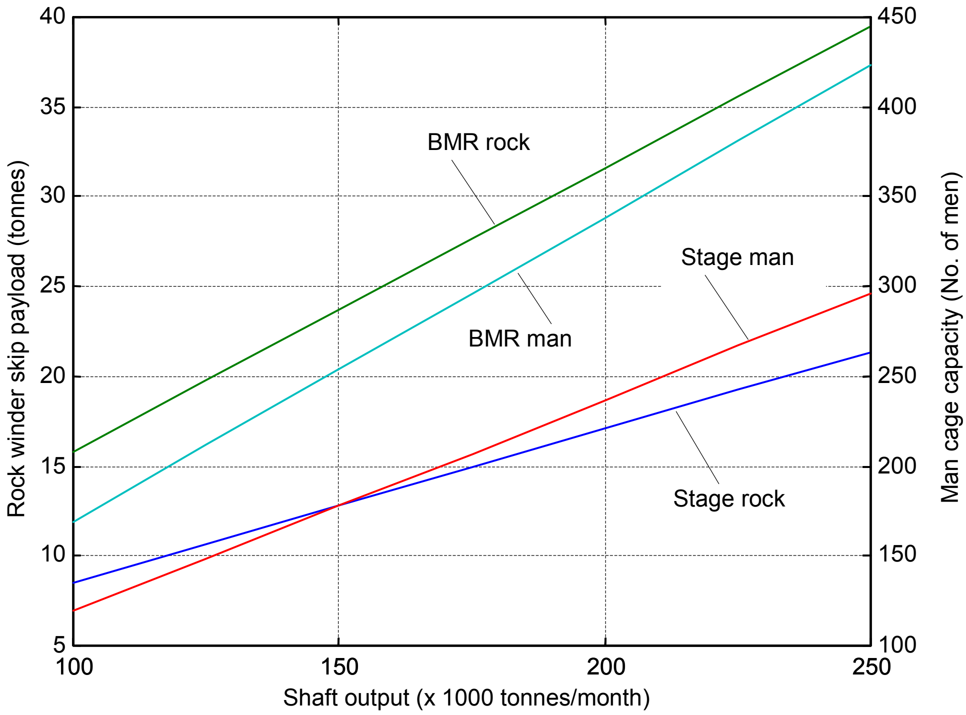


Figure 10 - Calculated conveyance capacities for various shaft output levels. Note that in the case of the man and rock Stage winders, there are two conveyances per shaft compartment and the values indicated are per conveyance.

3.3 Top and bottom rope diameters

The calculated top triangular strand rope and bottom spiral strand diameters are shown in Figure 11. The diameter values arise from a selection of rope and strand breaking strength to satisfy certain factor of safety requirements. It can be seen that the diameter trend of the Stage man winder top ropes is affected above 200 000 tonnes per month. This is as a result of some instability of the fit that was used to determine the relationship between MBL and diameter shown earlier in Figure 5b.

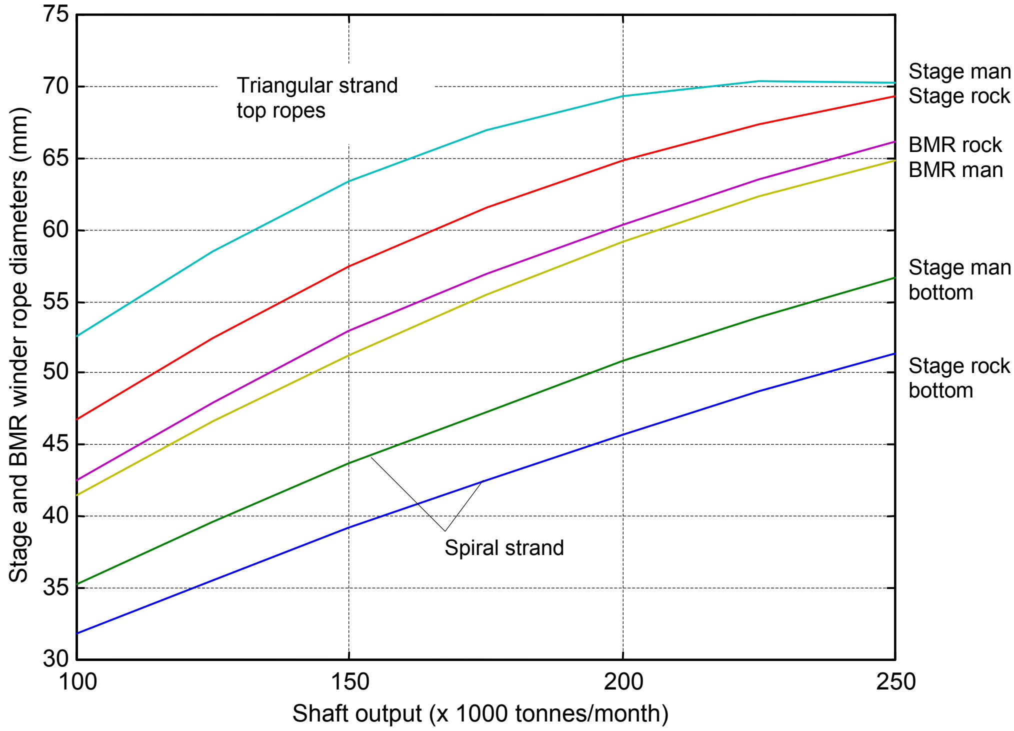


Figure 11 - Required top and bottom rope diameters. The Stage winders have a single spiral strand connecting the bottom conveyance to the underside of the top conveyance. Both BMR and Stage winders have two top ropes per shaft compartment as shown in Figure 1.

It should be noted that the rope selection factor or static factor of safety is influenced by the maximum suspended length of each section of rope. This resulted in a Stage winder bottom rope factor of 4.17, top rope factor of 4.12 and for the BMR top ropes 3.10. For determining permissible loading, these factors were applied to the minimum catalogue breaking loads of the rope and strand.

3.4 Winder drum diameters and associated inertia

Drum diameter, Figure 12a, is directly affected by the top rope diameter and, as was shown in Section 2.4, there is a strong relationship between the drum inertia and its diameter, Figure 12b. There is also a linear factor of drum compartment width in the inertia. The influence of the “unrealistic” relationship between the top rope diameter for the Stage man winder and its MBL is evident in Figure 12a and b. Referring back to Figure 9, which showed the motor ratings, it can however be seen that there is not any obvious change in trend as a result of the erroneous relationship. The likely explanation for this is that the suspended rope mass probably has a more marked effect on motor rating than the drum inertia where the relationship between mass and MBL (Figure 5a) was realistic (linear) throughout the calculation range.

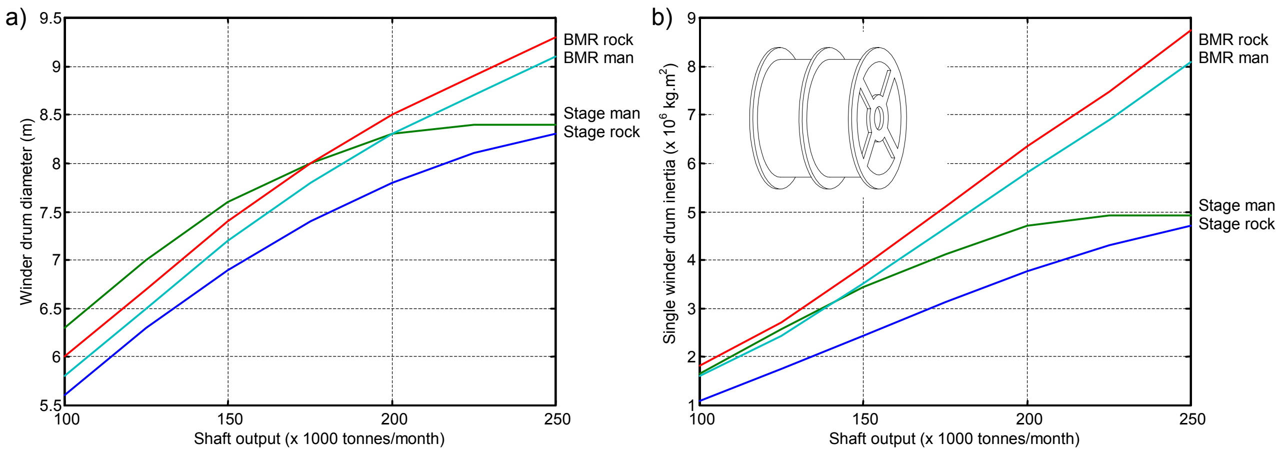


Figure 12 - Relationship between winder drum diameter (a) and inertia (b) and shaft output capacity. The change in trend for the Stage man winder is as a result of the unrealistic relationship between rope MBL and diameter for diameters above about 68 mm, shown in Figure 5b.

3.5 Effective conveyance masses and payloads

Looking at the configuration of the Stage winder (Figure 1b) it is clear that the winder is effectively a BMR type installation hoisting from a depth of 2000 m. The fact that a second conveyance is suspended in each compartment is not evident to the winder and top ropes. The bottom rope and bottom conveyance can be seen as an extension of the top conveyance which give access to hoisting depths of 4000 m. For the winder power calculations, it was therefore necessary to define what could be called effective conveyance mass and payload for the Stage winder. The effective payload is double the payload in each conveyance and the effective conveyance mass is the sum of the masses of the top conveyance, bottom rope and bottom conveyance. Figure 13 shows these masses for all the winders examined in this study.

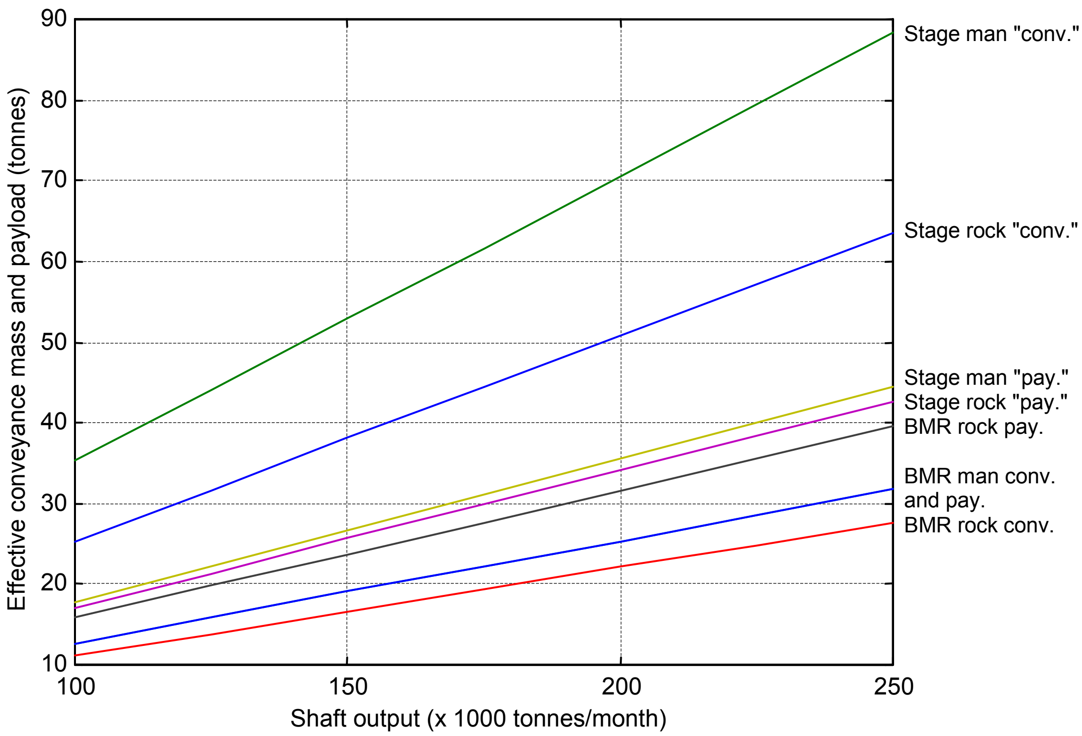


Figure 13 - Payloads and conveyance masses used in the winder drive power calculations. Note that for the Stage winders, the top conveyance, bottom rope and bottom conveyance are added together to form the effective conveyance mass. The Stage winder effective payload is the sum of the payload in the top and bottom conveyances.

Note that in the case of the BMR winders, with only single conveyances in each shaft compartment, the effective masses are just the conveyance masses and the single payloads.

3.6 Out of balance masses at the extreme positions of wind

Although the effective payloads and masses are higher for the Stage winders than for the BMR winders, the Stage winders are clearly more balanced at the extreme positions of the winds, Figure 14. It must be remembered that any mass which is part of the conveyance (e.g. the bottom ropes) occurs also in the adjacent shaft compartment. Since the two drums are on a (mechanically) common shaft, these masses balance each other out. The same is not true for the suspended top rope length and payload as these do not necessarily occur (suspended) at the same time in the adjacent shaft compartment.

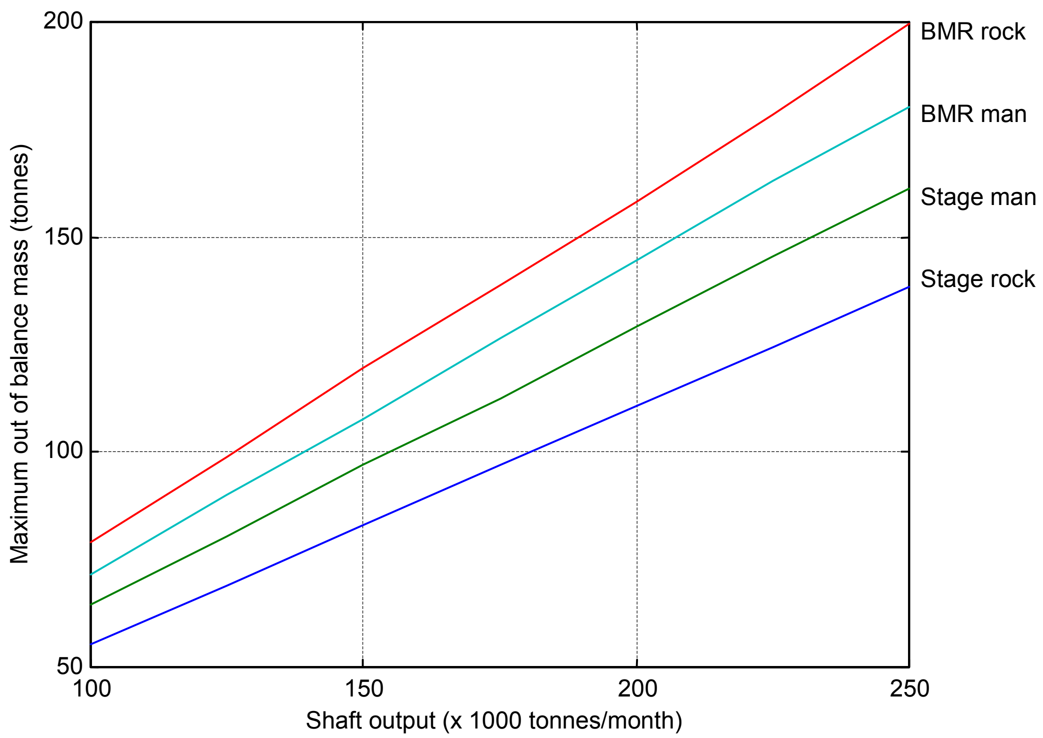


Figure 14 - Maximum out of balance masses as a function of shaft capacity for the four winding systems.

The BMR rock winders have on average a 43.5 % greater maximum out of balance mass than the Stage rock winders. For the BMR man winders the average maximum out of balance mass is 11.8 % more than the Stage man winders. The maximum out of balance mass was calculated knowing the out of balance (top) rope masses and total payload being hoisted.

4 DISCUSSION OF CALCULATION RESULTS

Motor power and winder drums

Considering rock winders, when using a Stage winder it is possible to get an extra 50 000 tonnes per month of rock out for a given RMS rating (Figure 9). This can clearly be seen by comparing the output of the Stage rock winder at say 20 MW RMS with the output of the BMR rock also at 20 MW RMS. It was also found that the maximum BMR rock winder motor RPM for all capacities was on average 7.7 % less than for the Stage rock winders. This implies physically smaller machines for the Stage rock winders. Motor RPM is directly related to drum diameter, so the smaller drums of the Stage rock winders inherently give faster motors which will be physically smaller (motor size being related to kW per RPM).

Power reduction advantages are not as significant for the Stage man winders which is probably as a result of the relatively high top cage factor (1.6) and the lower factor of safety which can be applied in the case of the 4000 m BMR winders.

The drum diameters and resulting inertias are not outside of what can be realistically achieved. Stage winders tend to have smaller drums which is related to the need for only having to store a maximum of around 2400 m per drum compartment compared to some 4400 m for the BMR winders.

Conveyance capacities

There is obviously a large difference in required conveyance payload capacity comparing the Stage with the BMR winders. Seeing that the BMR machines only have one conveyance in each compartment this was to be expected. In terms of the physical dimensions of the conveyances, the BMR ones really need to be a lot bigger as all the men and rock payload must be transported in a single conveyance. For a given vertical shaft diameter this is likely to limit the maximum output capacity (although doubling up on winders is a solution to this problem). At 250 000 tonnes per month the matching BMR man winder would require a cage capacity of 423 men where with the Stage winder the same could be achieved with 296 men cages (albeit two per compartment). The later number is probably within current design limits but 423 may be too large.

Split wind

Another issue where the Stage man winder may have an advantage over the 4000 m single lift BMR is the effect of air pressure change on the cage occupants. By forcing a change over between top and bottom cages at mid-shaft the occupants would be given some opportunity for pressure equalisation across the tympanic membrane in the ear. Fuller[9] recently examined these comfort (safety) pressure issues in the context of very long lift high speed building elevators. The natural mechanism of pressure equalisation is such that this is automatically achieved with ascending conveyances but the same is not true for the descent. Fuller showed that rapid altitude changes in excess of 1665 m could lead to tympanic membrane rupture. Based on current mine hoisting experience it is known that serious ear problems are not evident at single lift depths of up to 2500 m. It is not impossible that the change to 4000 m (especially at 19 m/s) could cause tympanic membrane differential pressure levels of higher than 10-20 kPa after which voluntary clearing is said to become difficult or impossible (which could then be followed by rupture). This information probably warrants more careful investigation prior to planning of a full 4000 m BMR man winder.

Ropes

The required rope diameters for the Stage and BMR winders are within current rope manufacturing technology (even up to 250 000 tonnes per month, Figure 11). Naturally the top ropes of the Stage winder are of larger diameter than for the BMR as a result of the higher factor of safety which is influenced by the shorter suspended length. The use of Lang's lay triangular strand ropes for drum winding in South Africa is very well established (significant experience in the manufacture, maintenance and condition monitoring) and so it would be useful if these ropes could be used for 4000 m deep shafts. By going the Stage winder route this is very feasible as the triangular strand ropes have been proven to be effective at suspended lengths of around 2000 m. The same can not be said for 4000 m where more sophisticated non-spin ropes will probably be required.

5 CONCLUSIONS

The purpose of this investigation was not to specifically promote one winding system above another but rather to present the likely technical specifications of the systems so that an objective comparison can be made. For conventional winding from 4000 m the BMR winders would most probably be the default option. The calculations have however shown that the Stage winder has the following potential advantages over the BMR :

- Quite significant reductions in motor power (and size) requirements.
- On average 30 % smaller cage and 46 % smaller skip payload capacities for all shaft outputs.
- Lower out of balance masses at the extreme positions of wind.

- Forced man changeover at the mid shaft position giving an opportunity for ear pressure equalisation.
- Possible reductions in capital costs due to less wire rope being used as well as smaller motors and winder drums.
- 2000 m less rope on the winder drum than the equivalent BMR winders and no rope development concerns as with the 4000 m BMR systems.

Some disadvantages include :

- Complexity of the mid shaft changeover system.
- Heavy top conveyances which are needed structurally to support the bottom conveyance and bottom rope.
- Higher static rope factors of safety due to the lower suspended rope lengths.
- Requirement for accurate positioning of adjacent top and bottom conveyances for payload transfer.

The final decision on which of these two systems would be the most suitable is complex and will be influenced by factors other than just the technical specifications of the winding plant. From a technical point of view, the main question to ask is whether the increased man, material and rock handling complexity at the mid-shaft position is warranted in light of the benefits which the Stage winder offers over the BMR machines ?

6 RECOMMENDATIONS

The effects of rope stretch on the positions of the top and bottom conveyances have to be investigated but it is expected that the stiffer spiral strand bottom “ropes” would reduce complications associated with this. The employment of conveyance holding devices are also likely to be very necessary.

The dynamics of the Stage winder conveyances (and ropes) during emergency braking and motor fault conditions need to be examined. Very high rope loads may be generated if the conveyances within a shaft compartment oscillate out of phase. Significant work has been done on the topic of rope dynamics and oscillations by drive manufacturers and major South African mining companies, as discussed by Lambie[10]. The findings have been implemented on very deep shaft BMR winders which will operate down to 3200 m. These winders feature full proportional brake control which minimises rope stresses and oscillations during emergency stops. For stage winders, additional work would be needed to include the fixed length bottom ropes in the control algorithms. Mechanical stresses due to motor and drive faults can also be minimised by the use of high speed DC circuit breakers in the motor circuits. Examples of the implementation of these protection systems have previously been described by Lewis[11].

A detailed capital cost study may give further insight into the benefits or not of choosing the Stage winding system over the BMR.

Since the bottom spiral strand section is not subject to the same degradation loading (bending and external plastic wear) as the top ropes it is possible that the static factor of safety could be reduced without any negative effects on overall system safety. Using high strength light weight materials for the Stage winder conveyances could also reduce the dead weight of the suspended assembly (i.e. better conveyance factors than the 0.7, 1.0, 1.1 and 1.6 which were assumed in this study). Such design improvements (modifications) could result in further benefits of Stage winding compared to full single lift BMR machines.

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8 ACKNOWLEDGEMENTS

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APPENDIX - **Numerical details, assumptions and calculation results for shafts capacities from 100 000 – 250 000 tonnes per month (14 pages). For each shaft capacity information is presented for Stage rock, Stage man, BMR rock and BMR man winders.**

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Normal Black = user entered values
Bold Black = calculated values

100 000 tonnes/month

	Stage Rock	Stage Man	BMR Rock	BMR Man
Maximum suspended top rope length, L (m)	2070	2070	4070	4070
Maximum winding distance (m)	**2050**	**2000**	**4050**	**4000**
Shaft rock capacity (tonnes/month)	100000	-	100000	-
U/G manpower requirement @ 40 tonnes / month / man	-	**2500**	-	**2500**
Rock / Man loading time (s)	10.0	180.0	10.0	180.0
Winder running time per trip, max speed = 19 m/s (s)	133.9	140.1	256.2	276.9
Maximum rock trips per month (26 days, 75 % utilisation)	**11708**	-	**6330**	-
Required payload per rock trip (tonnes) for given shaft rock capacity	**8.54**	-	**15.80**	-
Man cage capacity (no. of men) (80 % on day shift, all down in one and a half hours)	-	**119**	-	**169**
Required payload per trip (kN)	**83.8**	**87.6**	**155.0**	**124.3**
Bottom skip or cage factor (empty conveyance / payload) Including attachments	0.7	1.0	N/A	N/A
Top skip or cage factor (empty conveyance / payload) Including attachments	1.1	1.6	0.7	1.0
Bottom skip or cage weight, empty (kN)	**58.7**	**87.6**	N/A	N/A
Top skip or cage weight, empty (kN)	**92.2**	**140.1**	**108.5**	**124.3**
Bottom rope suspended length (m)	2000	2000	N/A	N/A
Maximum weight attached to bottom rope (kN)	**142.4**	**175.1**	N/A	N/A
Bottom rope breaking strength, Bridon, SS, 1770 MPa (kN)	1000	1230	N/A	N/A
Bottom rope mass per unit length [calculated] (kg/m)	**4.974**	**6.121**	N/A	N/A
Bottom rope diameter [calculated] (mm)	**31.8**	**35.3**	N/A	N/A
Bottom rope self weight, at max suspended length (kN)	**97.6**	**120.1**	N/A	N/A
Minimum allowed bottom rope selection factor 25000/(4000+L)	**4.17**	**4.17**	N/A	N/A
Actual bottom rope selection factor	**4.17**	**4.17**	N/A	N/A
Total weight attached to both top ropes (kN)	**416.0**	**522.8**	**263.4**	**248.7**
Total weight attached to one top rope (kN)	**208.0**	**261.4**	**131.7**	**124.3**
Top rope breaking strength, HRL, PTSR, 1900 MPa (kN)	1635	2060	1370	1300
Top rope mass per unit length [calculated] (kg/m)	**9.295**	**11.719**	**7.783**	**7.384**
Top rope diameter [calculated] (mm)	**46.7**	**52.6**	**42.6**	**41.5**
Top rope self weight, one rope only (kN) at max suspended length	**188.8**	**238.0**	**310.8**	**294.8**
Minimum allowed top rope selection factor 25000/(4000+L)	**4.12**	**4.12**	**3.10**	**3.10**
Actual top rope selection factor	**4.12**	**4.12**	**3.10**	**3.10**

Normal Black = user entered values
Bold Black = calculated values

	Stage Rock	Stage Man	BMR Rock	BMR Man
100 000 tonnes/month				
Drum / sheave to top rope diameter ratio (Minimum at 19 m/s = 116:1)	120	120	140	140
Drum diameter (m)	**5.6**	**6.3**	**6.0**	**5.8**
Head sheave diameter (m)	**5.6**	**6.3**	**6.0**	**5.8**
Drum compartment width (m)	1.6	1.6	2.1	2.1
Number of turns per layer (pitch = 1.055 d)	**32.5**	**28.8**	**46.7**	**48.0**
Total top rope length [L + 100 m + 15 dead turns] (m)	**2436**	**2469**	**4455**	**4445**
Maximum top rope length on drum (m) (total length - 120 m)	**2316**	**2349**	**4335**	**4325**
Maximum number of rope layers on drum (Max = 5, Min = 3)	**4**	**4**	**5**	**5**
Rope tread pressure on drum and sheave (MPa) P_tread = 2*F_max/(d_rope*D_drum) (Max = 3.5)	**3.03**	**3.01**	**3.46**	**3.49**
Effective conveyance empty weight for top ropes (kN)	**248.4**	**347.7**	**108.5**	**124.3**
for winder drive power calculations (tonnes)	**25.32**	**35.45**	**11.06**	**12.68**
Effective payload for the top ropes (kN)	**167.6**	**175.1**	**155.0**	**124.3**
for winder drive power calculations (tonnes)	**17.08**	**17.85**	**15.80**	**12.68**
Inertia per single drum (with 2 drum compartments) 1422.1 * $D\_drum^{3.5795}$ * Drum_comp_width ($kg.m^2$) rounded to nearest 1000	**1084000**	**1653000**	**1822000**	**1614000**
Inertia per single head sheave 112 * $D\_sheave^{3.2}$ ($kg.m^2$) rounded to nearest 100	**27800**	**40500**	**34600**	**31100**
Inertia per winder motor ($kg.m^2$)	25000	25000	30000	25000
Maximum out of balance mass (tonnes)	**55.19**	**64.73**	**78.84**	**71.75**
Number of winder motors	2	2	2	2
Total combined force ventilated RMS motor rating (kW)	8757	7259	10727	7867
Force ventilated RMS rating per motor (kW)	**4379**	**3630**	**5364**	**3934**
Total combined peak motor rating (kW)	18168	21666	20389	18840
Peak rating per motor (kW)	**9084**	**10833**	**10195**	**9420**
Maximum motor and drum speed (rpm) (rope speed = 19 m/s, radius = (D_drum + d_rope)/2	**64.3**	**57.1**	**60.1**	**62.1**

Additional information on drum layers :

	Stage Rock	Stage Man	BMR Rock	BMR Man
Top rope on 1st layer (m)	**576**	**575**	**887**	**881**
Top rope on 2nd layer (m)	**584**	**583**	**898**	**892**
Top rope on 3rd layer (m)	**592**	**591**	**908**	**902**
Top rope on 4th layer (m)	**600**	**600**	**919**	**913**
Top rope on 5th layer (m)	**608**	**608**	**930**	**924**
Top rope on 6th layer (m)	**617**	**616**	**940**	**934**

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125 000 tonnes/month

	Stage Rock	Stage Man	BMR Rock	BMR Man
Maximum suspended top rope length, L (m)	2070	2070	4070	4070
Maximum winding distance (m)	**2050**	**2000**	**4050**	**4000**
Shaft rock capacity (tonnes/month)	125000	-	125000	-
U/G manpower requirement @ 40 tonnes / month / man	-	**3125**	-	**3125**
Rock / Man loading time (s)	10.0	180.0	10.0	180.0
Winder running time per trip, max speed = 19 m/s (s)	133.9	140.1	256.2	276.9
Maximum rock trips per month (26 days, 75 % utilisation)	**11708**	-	**6330**	-
Required payload per rock trip (tonnes) for given shaft rock capacity	**10.68**	-	**19.75**	-
Man cage capacity (no. of men) (80 % on day shift, all down in one and a half hours)	-	**148**	-	**212**
Required payload per trip (kN)	**104.7**	**108.9**	**193.7**	**156.0**
Bottom skip or cage factor (empty conveyance / payload) Including attachments	0.7	1.0	N/A	N/A
Top skip or cage factor (empty conveyance / payload) Including attachments	1.1	1.6	0.7	1.0
Bottom skip or cage weight, empty (kN)	**73.3**	**108.9**	N/A	N/A
Top skip or cage weight, empty (kN)	**115.2**	**174.2**	**135.6**	**156.0**
Bottom rope suspended length (m)	2000	2000	N/A	N/A
Maximum weight attached to bottom rope (kN)	**178.0**	**217.8**	N/A	N/A
Bottom rope breaking strength, Bridon, SS, 1770 MPa (kN)	1250	1530	N/A	N/A
Bottom rope mass per unit length [calculated] (kg/m)	**6.220**	**7.616**	N/A	N/A
Bottom rope diameter [calculated] (mm)	**35.6**	**39.6**	N/A	N/A
Bottom rope self weight, at max suspended length (kN)	**122.0**	**149.4**	N/A	N/A
Minimum allowed bottom rope selection factor 25000/(4000+L)	**4.17**	**4.17**	N/A	N/A
Actual bottom rope selection factor	**4.17**	**4.17**	N/A	N/A
Total weight attached to both top ropes (kN)	**520.0**	**650.3**	**329.3**	**312.0**
Total weight attached to one top rope (kN)	**260.0**	**325.2**	**164.7**	**156.0**
Top rope breaking strength, HRL, PTSR, 1900 MPa (kN)	2040	2560	1720	1630
Top rope mass per unit length [calculated] (kg/m)	**11.605**	**14.571**	**9.780**	**9.267**
Top rope diameter [calculated] (mm)	**52.4**	**58.5**	**48.0**	**46.6**
Top rope self weight, one rope only (kN) at max suspended length	**235.7**	**295.9**	**390.5**	**370.0**
Minimum allowed top rope selection factor 25000/(4000+L)	**4.12**	**4.12**	**3.10**	**3.10**
Actual top rope selection factor	**4.12**	**4.12**	**3.10**	**3.10**

Normal Black = user entered values **Bold Black** = calculated values	**Stage Rock**	**Stage Man**	**BMR Rock**	**BMR Man**
125 000 tonnes/month				
Drum / sheave to top rope diameter ratio (Minimum at 19 m/s = 116:1)	120	120	140	140
Drum diameter (m)	**6.3**	**7.0**	**6.7**	**6.5**
Head sheave diameter (m)	**6.3**	**7.0**	**6.7**	**6.5**
Drum compartment width (m)	1.7	1.7	2.1	2.1
Number of turns per layer (pitch = 1.055 d)	**30.8**	**27.5**	**41.5**	**42.7**
Total top rope length [L + 100 m + 15 dead turns] (m)	**2469**	**2503**	**4488**	**4479**
Maximum top rope length on drum (m) (total length - 120 m)	**2349**	**2383**	**4368**	**4359**
Maximum number of rope layers on drum (Max = 5, Min = 3)	**4**	**4**	**5**	**5**
Rope tread pressure on drum and sheave (MPa) P_tread = 2*F_max/(d_rope*D_drum) (Max = 3.5)	**3.01**	**3.03**	**3.46**	**3.47**
Effective conveyance empty weight for top ropes (kN) for winder drive power calculations (tonnes)	**310.6** **31.66**	**432.5** **44.09**	**135.6** **13.82**	**156.0** **15.90**
Effective payload for the top ropes (kN) for winder drive power calculations (tonnes)	**209.5** **21.35**	**217.8** **22.20**	**193.7** **19.75**	**156.0** **15.90**
Inertia per single drum (with 2 drum compartments) 1422.1 * $D\_drum^{3.5795}$ * Drum_comp_width (kg.m^2) rounded to nearest 1000	**1756000**	**2561000**	**2704000**	**2426000**
Inertia per single head sheave 112 * $D\_sheave^{3.2}$ (kg.m^2) rounded to nearest 100	**40500**	**56700**	**49300**	**44700**
Inertia per winder motor (kg.m^2)	40000	40000	65000	50000
Maximum out of balance mass (tonnes)	**68.93**	**80.49**	**98.96**	**90.03**
Number of winder motors	2	2	2	2
Total combined force ventilated RMS motor rating (kW)	10995	9042	13338	9784
Force ventilated RMS rating per motor (kW)	**5498**	**4521**	**6669**	**4892**
Total combined peak motor rating (kW)	22816	26991	25370	23444
Peak rating per motor (kW)	**11408**	**13496**	**12685**	**11722**
Maximum motor and drum speed (rpm) (rope speed = 19 m/s, radius = (D_drum + d_rope)/2	**57.1**	**51.4**	**53.8**	**55.4**
Additional information on drum layers :				
Top rope on 1st layer (m)	**614**	**611**	**880**	**878**
Top rope on 2nd layer (m)	**623**	**619**	**891**	**889**
Top rope on 3rd layer (m)	**631**	**628**	**901**	**899**
Top rope on 4th layer (m)	**640**	**637**	**912**	**910**
Top rope on 5th layer (m)	**649**	**645**	**922**	**920**
Top rope on 6th layer (m)	**657**	**654**	**933**	**931**

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Normal Black = user entered values
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150 000 tonnes/month

	Stage Rock	Stage Man	BMR Rock	BMR Man
Maximum suspended top rope length, L (m)	2070	2070	4070	4070
Maximum winding distance (m)	**2050**	**2000**	**4050**	**4000**
Shaft rock capacity (tonnes/month)	150000	-	150000	-
U/G manpower requirement @ 40 tonnes / month / man	-	**3750**	-	**3750**
Rock / Man loading time (s)	10.0	180.0	10.0	180.0
Winder running time per trip, max speed = 19 m/s (s)	133.9	140.1	256.2	276.9
Maximum rock trips per month (26 days, 75 % utilisation)	**11708**	-	**6330**	-
Required payload per rock trip (tonnes) for given shaft rock capacity	**12.81**	-	**23.70**	-
Man cage capacity (no. of men) (80 % on day shift, all down in one and a half hours)	-	**178**	-	**254**
Required payload per trip (kN)	**125.7**	**131.0**	**232.5**	**186.9**
Bottom skip or cage factor (empty conveyance / payload) Including attachments	0.7	1.0	N/A	N/A
Top skip or cage factor (empty conveyance / payload) Including attachments	1.1	1.6	0.7	1.0
Bottom skip or cage weight, empty (kN)	**88.0**	**131.0**	N/A	N/A
Top skip or cage weight, empty (kN)	**138.3**	**209.5**	**162.7**	**186.9**
Bottom rope suspended length (m)	2000	2000	N/A	N/A
Maximum weight attached to bottom rope (kN)	**213.7**	**261.9**	N/A	N/A
Bottom rope breaking strength, Bridon, SS, 1770 MPa (kN)	1505	1840	N/A	N/A
Bottom rope mass per unit length [calculated] (kg/m)	**7.492**	**9.162**	N/A	N/A
Bottom rope diameter [calculated] (mm)	**39.3**	**43.7**	N/A	N/A
Bottom rope self weight, at max suspended length (kN)	**147.0**	**179.8**	N/A	N/A
Minimum allowed bottom rope selection factor 25000/(4000+L)	**4.17**	**4.17**	N/A	N/A
Actual bottom rope selection factor	**4.17**	**4.17**	N/A	N/A
Total weight attached to both top ropes (kN)	**624.6**	**782.2**	**395.2**	**373.8**
Total weight attached to one top rope (kN)	**312.3**	**391.1**	**197.6**	**186.9**
Top rope breaking strength, HRL, PTSR, 1900 MPa (kN)	2460	3080	2080	1950
Top rope mass per unit length [calculated] (kg/m)	**14.001**	**17.537**	**11.833**	**11.092**
Top rope diameter [calculated] (mm)	**57.4**	**63.4**	**52.9**	**51.2**
Top rope self weight, one rope only (kN) at max suspended length	**284.3**	**356.1**	**472.5**	**442.9**
Minimum allowed top rope selection factor 25000/(4000+L)	**4.12**	**4.12**	**3.10**	**3.10**
Actual top rope selection factor	**4.12**	**4.12**	**3.10**	**3.10**

Normal Black = user entered values
Bold Black = calculated values

150 000 tonnes/month	**Stage Rock**	**Stage Man**	**BMR Rock**	**BMR Man**
Drum / sheave to top rope diameter ratio (Minimum at 19 m/s = 116:1)	120	120	140	140
Drum diameter (m)	**6.9**	**7.6**	**7.4**	**7.2**
Head sheave diameter (m)	**6.9**	**7.6**	**7.4**	**7.2**
Drum compartment width (m)	1.7	1.7	2.1	2.1
Number of turns per layer (pitch = 1.055 d)	**28.1**	**25.4**	**37.6**	**38.9**
Total top rope length [L + 100 m + 15 dead turns] (m)	**2498**	**2531**	**4521**	**4512**
Maximum top rope length on drum (m) (total length - 120 m)	**2378**	**2411**	**4401**	**4392**
Maximum number of rope layers on drum (Max = 5, Min = 3)	**4**	**4**	**5**	**5**
Rope tread pressure on drum and sheave (MPa) P_tread = 2*F_max/(d_rope*D_drum) (Max = 3.5)	**3.01**	**3.10**	**3.42**	**3.42**
Effective conveyance empty weight for top ropes (kN) for winder drive power calculations (tonnes)	**373.2** **38.04**	**520.3** **53.03**	**162.7** **16.59**	**186.9** **19.05**
Effective payload for the top ropes (kN) for winder drive power calculations (tonnes)	**251.4** **25.62**	**261.9** **26.70**	**232.5** **23.70**	**186.9** **19.05**
Inertia per single drum (with 2 drum compartments) 1422.1 * $D\_drum^{3.5795}$ * Drum_comp_width (kg.m^2) rounded to nearest 1000	**2432000**	**3438000**	**3860000**	**3499000**
Inertia per single head sheave 112 * $D\_sheave^{3.2}$ (kg.m^2) rounded to nearest 100	**54100**	**73800**	**67700**	**62000**
Inertia per winder motor (kg.m^2)	40000	40000	65000	50000
Maximum out of balance mass (tonnes)	**83.03**	**96.85**	**119.55**	**107.78**
Number of winder motors	2	2	2	2
Total combined force ventilated RMS motor rating (kW)	13030	10725	15995	11604
Force ventilated RMS rating per motor (kW)	**6515**	**5363**	**7998**	**5802**
Total combined peak motor rating (kW)	27013	31972	30431	27822
Peak rating per motor (kW)	**13507**	**15986**	**15216**	**13911**
Maximum motor and drum speed (rpm) (rope speed = 19 m/s, radius = (D_drum + d_rope)/2	**52.2**	**47.4**	**48.7**	**50.0**

Additional information on drum layers :

Top rope on 1st layer (m)	**613**	**612**	**881**	**886**
Top rope on 2nd layer (m)	**622**	**621**	**892**	**897**
Top rope on 3rd layer (m)	**631**	**629**	**903**	**907**
Top rope on 4th layer (m)	**639**	**638**	**913**	**918**
Top rope on 5th layer (m)	**648**	**647**	**924**	**929**
Top rope on 6th layer (m)	**657**	**655**	**935**	**939**

Normal Black = user entered values
Bold Black = calculated values

175 000 tonnes/month

	Stage Rock	Stage Man	BMR Rock	BMR Man
Maximum suspended top rope length, L (m)	2070	2070	4070	4070
Maximum winding distance (m)	**2050**	**2000**	**4050**	**4000**
Shaft rock capacity (tonnes/month)	175000	-	175000	-
U/G manpower requirement @ 40 tonnes / month / man	-	**4375**	-	**4375**
Rock / Man loading time (s)	10.0	180.0	10.0	180.0
Winder running time per trip, max speed = 19 m/s (s)	133.9	140.1	256.2	276.9
Maximum rock trips per month (26 days, 75 % utilisation)	**11708**	-	**6330**	-
Required payload per rock trip (tonnes) for given shaft rock capacity	**14.95**	-	**27.64**	-
Man cage capacity (no. of men) (80 % on day shift, all down in one and a half hours)	-	**207**	-	**296**
Required payload per trip (kN)	**146.6**	**152.3**	**271.2**	**217.8**
Bottom skip or cage factor (empty conveyance / payload) Including attachments	0.7	1.0	N/A	N/A
Top skip or cage factor (empty conveyance / payload) Including attachments	1.1	1.6	0.7	1.0
Bottom skip or cage weight, empty (kN)	**102.6**	**152.3**	N/A	N/A
Top skip or cage weight, empty (kN)	**161.3**	**243.7**	**189.8**	**217.8**
Bottom rope suspended length (m)	2000	2000	N/A	N/A
Maximum weight attached to bottom rope (kN)	**249.3**	**304.6**	N/A	N/A
Bottom rope breaking strength, Bridon, SS, 1770 MPa (kN)	1755	2140	N/A	N/A
Bottom rope mass per unit length [calculated] (kg/m)	**8.738**	**10.657**	N/A	N/A
Bottom rope diameter [calculated] (mm)	**42.6**	**47.3**	N/A	N/A
Bottom rope self weight, at max suspended length (kN)	**171.4**	**209.1**	N/A	N/A
Minimum allowed bottom rope selection factor 25000/(4000+L)	**4.17**	**4.17**	N/A	N/A
Actual bottom rope selection factor	**4.17**	**4.17**	N/A	N/A
Total weight attached to both top ropes (kN)	**728.6**	**909.7**	**461.0**	**435.6**
Total weight attached to one top rope (kN)	**364.3**	**454.8**	**230.5**	**217.8**
Top rope breaking strength, HRL, PTSR, 1900 MPa (kN)	2870	3580	2410	2290
Top rope mass per unit length [calculated] (kg/m)	**16.340**	**20.390**	**13.716**	**13.031**
Top rope diameter [calculated] (mm)	**61.5**	**66.9**	**56.9**	**55.5**
Top rope self weight, one rope only (kN) at max suspended length	**331.8**	**414.0**	**547.6**	**520.3**
Minimum allowed top rope selection factor 25000/(4000+L)	**4.12**	**4.12**	**3.10**	**3.10**
Actual top rope selection factor	**4.12**	**4.12**	**3.10**	**3.10**

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175 000 tonnes/month

	Stage Rock	Stage Man	BMR Rock	BMR Man
Drum / sheave to top rope diameter ratio (Minimum at 19 m/s = 116:1)	120	120	140	140
Drum diameter (m)	**7.4**	**8.0**	**8.0**	**7.8**
Head sheave diameter (m)	**7.4**	**8.0**	**8.0**	**7.8**
Drum compartment width (m)	1.7	1.7	2.1	2.1
Number of turns per layer (pitch = 1.055 d)	**26.2**	**24.1**	**35.0**	**35.9**
Total top rope length [L + 100 m + 15 dead turns] (m)	**2522**	**2550**	**4550**	**4540**
Maximum top rope length on drum (m) (total length - 120 m)	**2402**	**2430**	**4430**	**4420**
Maximum number of rope layers on drum (Max = 5, Min = 3)	**4**	**4**	**5**	**5**
Rope tread pressure on drum and sheave (MPa) P_tread = 2*F_max/(d_rope*D_drum) (Max = 3.5)	**3.06**	**3.25**	**3.42**	**3.41**
Effective conveyance empty weight for top ropes (kN)	**435.4**	**605.1**	**189.8**	**217.8**
for winder drive power calculations (tonnes)	**44.38**	**61.68**	**19.35**	**22.20**
Effective payload for the top ropes (kN)	**293.3**	**304.6**	**271.2**	**217.8**
for winder drive power calculations (tonnes)	**29.89**	**31.05**	**27.64**	**22.20**
Inertia per single drum (with 2 drum compartments) $1422.1 * D\_drum^{3.5795} * Drum\_comp\_width$ ($kg.m^2$) rounded to nearest 1000	**3125000**	**4130000**	**5102000**	**4660000**
Inertia per single head sheave $112 * D\_sheave^{3.2}$ ($kg.m^2$) rounded to nearest 100	**67700**	**86900**	**86900**	**80200**
Inertia per winder motor ($kg.m^2$)	50000	50000	75000	60000
Maximum out of balance mass (tonnes)	**96.89**	**112.61**	**138.74**	**126.45**
Number of winder motors	2	2	2	2
Total combined force ventilated RMS motor rating (kW)	15042	12274	18457	13528
Force ventilated RMS rating per motor (kW)	**7521**	**6137**	**9229**	**6764**
Total combined peak motor rating (kW)	31170	36537	35152	32431
Peak rating per motor (kW)	**15585**	**18269**	**17576**	**16216**
Maximum motor and drum speed (rpm) (rope speed = 19 m/s, radius = (D_drum + d_rope)/2	**48.6**	**45.0**	**45.0**	**46.2**

Additional information on drum layers :

	Stage Rock	Stage Man	BMR Rock	BMR Man
Top rope on 1st layer (m)	**614**	**611**	**886**	**886**
Top rope on 2nd layer (m)	**622**	**619**	**897**	**896**
Top rope on 3rd layer (m)	**631**	**628**	**907**	**907**
Top rope on 4th layer (m)	**640**	**637**	**918**	**918**
Top rope on 5th layer (m)	**648**	**645**	**929**	**928**
Top rope on 6th layer (m)	**657**	**654**	**939**	**939**

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200 000 tonnes/month

	Stage Rock	Stage Man	BMR Rock	BMR Man
Maximum suspended top rope length, L (m)	2070	2070	4070	4070
Maximum winding distance (m)	**2050**	**2000**	**4050**	**4000**
Shaft rock capacity (tonnes/month)	200000	-	200000	-
U/G manpower requirement @ 40 tonnes / month / man	-	**5000**	-	**5000**
Rock / Man loading time (s)	10.0	180.0	10.0	180.0
Winder running time per trip, max speed = 19 m/s (s)	133.9	140.1	256.2	276.9
Maximum rock trips per month (26 days, 75 % utilisation)	**11708**	-	**6330**	-
Required payload per rock trip (tonnes) for given shaft rock capacity	**17.08**	-	**31.59**	-
Man cage capacity (no. of men) (80 % on day shift, all down in one and a half hours)	-	**237**	-	**338**
Required payload per trip (kN)	**167.6**	**174.4**	**309.9**	**248.7**
Bottom skip or cage factor (empty conveyance / payload) Including attachments	0.7	1.0	N/A	N/A
Top skip or cage factor (empty conveyance / payload) Including attachments	1.1	1.6	0.7	1.0
Bottom skip or cage weight, empty (kN)	**117.3**	**174.4**	N/A	N/A
Top skip or cage weight, empty (kN)	**184.3**	**279.0**	**217.0**	**248.7**
Bottom rope suspended length (m)	2000	2000	N/A	N/A
Maximum weight attached to bottom rope (kN)	**284.9**	**348.7**	N/A	N/A
Bottom rope breaking strength, Bridon, SS, 1770 MPa (kN)	2005	2450	N/A	N/A
Bottom rope mass per unit length [calculated] (kg/m)	**9.984**	**12.203**	N/A	N/A
Bottom rope diameter [calculated] (mm)	**45.7**	**50.8**	N/A	N/A
Bottom rope self weight, at max suspended length (kN)	**195.9**	**239.4**	N/A	N/A
Minimum allowed bottom rope selection factor 25000/(4000+L)	**4.17**	**4.17**	N/A	N/A
Actual bottom rope selection factor	**4.17**	**4.17**	N/A	N/A
Total weight attached to both top ropes (kN)	**832.7**	**1041.5**	**526.9**	**497.4**
Total weight attached to one top rope (kN)	**416.3**	**520.8**	**263.4**	**248.7**
Top rope breaking strength, HRL, PTSR, 1900 MPa (kN)	3280	4100	2750	2620
Top rope mass per unit length [calculated] (kg/m)	**18.678**	**23.356**	**15.655**	**14.914**
Top rope diameter [calculated] (mm)	**64.9**	**69.3**	**60.4**	**59.1**
Top rope self weight, one rope only (kN) at max suspended length	**379.3**	**474.3**	**625.1**	**595.5**
Minimum allowed top rope selection factor 25000/(4000+L)	**4.12**	**4.12**	**3.10**	**3.10**
Actual top rope selection factor	**4.12**	**4.12**	**3.10**	**3.10**

Normal Black = user entered values
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200 000 tonnes/month

	Stage Rock	Stage Man	BMR Rock	BMR Man
Drum / sheave to top rope diameter ratio (Minimum at 19 m/s = 116:1)	120	120	140	140
Drum diameter (m)	**7.8**	**8.3**	**8.5**	**8.3**
Head sheave diameter (m)	**7.8**	**8.3**	**8.5**	**8.3**
Drum compartment width (m)	1.7	1.7	2.1	2.1
Number of turns per layer (pitch = 1.055 d)	**24.8**	**23.3**	**32.9**	**33.7**
Total top rope length [L + 100 m + 15 dead turns] (m)	**2541**	**2564**	**4573**	**4564**
Maximum top rope length on drum (m) (total length - 120 m)	**2421**	**2444**	**4453**	**4444**
Maximum number of rope layers on drum (Max = 5, Min = 3)	**4**	**4**	**5**	**5**
Rope tread pressure on drum and sheave (MPa) P_tread = 2*F_max/(d_rope*D_drum) (Max = 3.5)	**3.14**	**3.46**	**3.46**	**3.44**
Effective conveyance empty weight for top ropes (kN)	**497.5**	**692.8**	**217.0**	**248.7**
for winder drive power calculations (tonnes)	**50.72**	**70.62**	**22.12**	**25.35**
Effective payload for the top ropes (kN)	**335.2**	**348.7**	**309.9**	**248.7**
for winder drive power calculations (tonnes)	**34.16**	**35.55**	**31.59**	**25.35**
Inertia per single drum (with 2 drum compartments) 1422.1 * $D\_drum^{3.5795}$ * Drum_comp_width (kg.m^2) rounded to nearest 1000	**3773000**	**4712000**	**6339000**	**5821000**
Inertia per single head sheave 112 * $D\_sheave^{3.2}$ (kg.m^2) rounded to nearest 100	**80200**	**97800**	**105500**	**97800**
Inertia per winder motor (kg.m^2)	50000	50000	75000	60000
Maximum out of balance mass (tonnes)	**110.75**	**128.97**	**158.40**	**144.66**
Number of winder motors	2	2	2	2
Total combined force ventilated RMS motor rating (kW)	16984	13785	20916	15367
Force ventilated RMS rating per motor (kW)	**8492**	**6893**	**10458**	**7684**
Total combined peak motor rating (kW)	35176	40946	39869	36849
Peak rating per motor (kW)	**17588**	**20473**	**19935**	**18425**
Maximum motor and drum speed (rpm) (rope speed = 19 m/s, radius = (D_drum + d_rope)/2	**46.1**	**43.4**	**42.4**	**43.4**

Additional information on drum layers :

	Stage Rock	Stage Man	BMR Rock	BMR Man
Top rope on 1st layer (m)	**613**	**612**	**886**	**884**
Top rope on 2nd layer (m)	**622**	**620**	**897**	**895**
Top rope on 3rd layer (m)	**631**	**629**	**907**	**905**
Top rope on 4th layer (m)	**639**	**638**	**918**	**916**
Top rope on 5th layer (m)	**648**	**646**	**929**	**927**
Top rope on 6th layer (m)	**656**	**655**	**939**	**937**

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225 000 tonnes/month

	Stage Rock	Stage Man	BMR Rock	BMR Man
Maximum suspended top rope length, L (m)	2070	2070	4070	4070
Maximum winding distance (m)	**2050**	**2000**	**4050**	**4000**
Shaft rock capacity (tonnes/month)	225000	-	225000	-
U/G manpower requirement @ 40 tonnes / month / man	-	**5625**	-	**5625**
Rock / Man loading time (s)	10.0	180.0	10.0	180.0
Winder running time per trip, max speed = 19 m/s (s)	133.9	140.1	256.2	276.9
Maximum rock trips per month (26 days, 75 % utilisation)	**11708**	-	**6330**	-
Required payload per rock trip (tonnes) for given shaft rock capacity	**19.22**	-	**35.54**	-
Man cage capacity (no. of men) (80 % on day shift, all down in one and a half hours)	-	**267**	-	**381**
Required payload per trip (kN)	**188.5**	**196.4**	**348.7**	**280.3**
Bottom skip or cage factor (empty conveyance / payload) Including attachments	0.7	1.0	N/A	N/A
Top skip or cage factor (empty conveyance / payload) Including attachments	1.1	1.6	0.7	1.0
Bottom skip or cage weight, empty (kN)	**132.0**	**196.4**	N/A	N/A
Top skip or cage weight, empty (kN)	**207.4**	**314.3**	**244.1**	**280.3**
Bottom rope suspended length (m)	2000	2000	N/A	N/A
Maximum weight attached to bottom rope (kN)	**320.5**	**392.9**	N/A	N/A
Bottom rope breaking strength, Bridon, SS, 1770 MPa (kN)	2260	2760	N/A	N/A
Bottom rope mass per unit length [calculated] (kg/m)	**11.255**	**13.748**	N/A	N/A
Bottom rope diameter [calculated] (mm)	**48.7**	**53.9**	N/A	N/A
Bottom rope self weight, at max suspended length (kN)	**220.8**	**269.7**	N/A	N/A
Minimum allowed bottom rope selection factor 25000/(4000+L)	**4.17**	**4.17**	N/A	N/A
Actual bottom rope selection factor	**4.17**	**4.17**	N/A	N/A
Total weight attached to both top ropes (kN)	**937.2**	**1173.4**	**592.8**	**560.6**
Total weight attached to one top rope (kN)	**468.6**	**586.7**	**296.4**	**280.3**
Top rope breaking strength, HRL, PTSR, 1900 MPa (kN)	3680	4620	3100	2950
Top rope mass per unit length [calculated] (kg/m)	**20.960**	**26.322**	**17.652**	**16.796**
Top rope diameter [calculated] (mm)	**67.4**	**70.4**	**63.5**	**62.3**
Top rope self weight, one rope only (kN) at max suspended length	**425.6**	**534.5**	**704.8**	**670.6**
Minimum allowed top rope selection factor 25000/(4000+L)	**4.12**	**4.12**	**3.10**	**3.10**
Actual top rope selection factor	**4.12**	**4.12**	**3.10**	**3.10**

Normal Black = user entered values
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225 000 tonnes/month	**Stage Rock**	**Stage Man**	**BMR Rock**	**BMR Man**
Drum / sheave to top rope diameter ratio (Minimum at 19 m/s = 116:1)	120	120	140	140
Drum diameter (m)	**8.1**	**8.4**	**8.9**	**8.7**
Head sheave diameter (m)	**8.1**	**8.4**	**8.9**	**8.7**
Drum compartment width (m)	1.7	1.7	2.1	2.1
Number of turns per layer (pitch = 1.055 d)	**23.9**	**22.9**	**31.3**	**32.0**
Total top rope length [L + 100 m + 15 dead turns] (m)	**2555**	**2569**	**4592**	**4583**
Maximum top rope length on drum (m) (total length - 120 m)	**2435**	**2449**	**4472**	**4463**
Maximum number of rope layers on drum (Max = 5, Min = 3)	**4**	**4**	**5**	**5**
Rope tread pressure on drum and sheave (MPa) P_tread = 2*F_max/(d_rope*D_drum) (Max = 3.5)	**3.28**	**3.79**	**3.54**	**3.51**
Effective conveyance empty weight for top ropes (kN)	**560.2**	**780.5**	**244.1**	**280.3**
for winder drive power calculations (tonnes)	**57.10**	**79.56**	**24.88**	**28.58**
Effective payload for the top ropes (kN)	**377.0**	**392.9**	**348.7**	**280.3**
for winder drive power calculations (tonnes)	**38.43**	**40.05**	**35.54**	**28.58**
Inertia per single drum (with 2 drum compartments) 1422.1 * D_drum$^{3.5795}$ * Drum_comp_width (kg.m^2) rounded to nearest 1000	**4318000**	**4919000**	**7473000**	**6889000**
Inertia per single head sheave 112 * D_sheave$^{3.2}$ (kg.m^2) rounded to nearest 100	**90400**	**101600**	**122300**	**113700**
Inertia per winder motor (kg.m^2)	50000	50000	75000	60000
Maximum out of balance mass (tonnes)	**124.37**	**145.34**	**178.52**	**162.94**
Number of winder motors	2	2	2	2
Total combined force ventilated RMS motor rating (kW)	18831	15238	23369	17169
Force ventilated RMS rating per motor (kW)	**9415.5**	**7619.0**	**11684.5**	**8584.5**
Total combined peak motor rating (kW)	38978	45162	44577	41189
Peak rating per motor (kW)	**19489**	**22581**	**22289**	**20595**
Maximum motor and drum speed (rpm) (rope speed = 19 m/s, radius = (D_drum + d_rope)/2	**44.4**	**42.8**	**40.5**	**41.4**

Additional information on drum layers :

Top rope on 1st layer (m)	**613**	**609**	**882**	**880**
Top rope on 2nd layer (m)	**622**	**618**	**893**	**891**
Top rope on 3rd layer (m)	**631**	**626**	**904**	**901**
Top rope on 4th layer (m)	**639**	**635**	**914**	**912**
Top rope on 5th layer (m)	**648**	**644**	**925**	**923**
Top rope on 6th layer (m)	**656**	**652**	**936**	**933**

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250 000 tonnes/month	**Stage Rock**	**Stage Man**	**BMR Rock**	**BMR Man**
Maximum suspended top rope length, L (m)	2070	2070	4070	4070
Maximum winding distance (m)	**2050**	**2000**	**4050**	**4000**
Shaft rock capacity (tonnes/month)	250000	-	250000	-
U/G manpower requirement @ 40 tonnes / month / man	-	**6250**	-	**6250**
Rock / Man loading time (s)	10.0	180.0	10.0	180.0
Winder running time per trip, max speed = 19 m/s (s)	133.9	140.1	256.2	276.9
Maximum rock trips per month (26 days, 75 % utilisation)	**11708**	-	**6330**	-
Required payload per rock trip (tonnes) for given shaft rock capacity	**21.35**	-	**39.49**	-
Man cage capacity (no. of men) (80 % on day shift, all down in one and a half hours)	-	**296**	-	**423**
Required payload per trip (kN)	**209.5**	**217.8**	**387.4**	**311.2**
Bottom skip or cage factor (empty conveyance / payload) Including attachments	0.7	1.0	N/A	N/A
Top skip or cage factor (empty conveyance / payload) Including attachments	1.1	1.6	0.7	1.0
Bottom skip or cage weight, empty (kN)	**146.6**	**217.8**	N/A	N/A
Top skip or cage weight, empty (kN)	**230.4**	**348.5**	**271.2**	**311.2**
Bottom rope suspended length (m)	2000	2000	N/A	N/A
Maximum weight attached to bottom rope (kN)	**356.1**	**435.6**	N/A	N/A
Bottom rope breaking strength, Bridon, SS, 1770 MPa (kN)	2510	3070	N/A	N/A
Bottom rope mass per unit length [calculated] (kg/m)	**12.502**	**15.293**	N/A	N/A
Bottom rope diameter [calculated] (mm)	**51.4**	**56.7**	N/A	N/A
Bottom rope self weight, at max suspended length (kN)	**245.3**	**300.1**	N/A	N/A
Minimum allowed bottom rope selection factor 25000/(4000+L)	**4.17**	**4.17**	N/A	N/A
Actual bottom rope selection factor	**4.17**	**4.17**	N/A	N/A
Total weight attached to both top ropes (kN)	**1041.3**	**1301.9**	**658.6**	**622.4**
Total weight attached to one top rope (kN)	**520.6**	**650.9**	**329.3**	**311.2**
Top rope breaking strength, HRL, PTSR, 1900 MPa (kN)	4100	5130	3470	3260
Top rope mass per unit length [calculated] (kg/m)	**23.356**	**29.231**	**19.762**	**18.564**
Top rope diameter [calculated] (mm)	**69.3**	**70.3**	**66.2**	**64.8**
Top rope self weight, one rope only (kN) at max suspended length	**474.3**	**593.6**	**789.0**	**741.2**
Minimum allowed top rope selection factor 25000/(4000+L)	**4.12**	**4.12**	**3.10**	**3.10**
Actual top rope selection factor	**4.12**	**4.12**	**3.10**	**3.10**

Normal Black = user entered values
Bold Black = calculated values

250 000 tonnes/month	**Stage Rock**	**Stage Man**	**BMR Rock**	**BMR Man**
Drum / sheave to top rope diameter ratio (Minimum at 19 m/s = 116:1)	120	120	140	140
Drum diameter (m)	**8.3**	**8.4**	**9.3**	**9.1**
Head sheave diameter (m)	**8.3**	**8.4**	**9.3**	**9.1**
Drum compartment width (m)	1.7	1.7	2.1	2.1
Number of turns per layer (pitch = 1.055 d)	**23.3**	**22.9**	**30.1**	**30.7**
Total top rope length [L + 100 m + 15 dead turns] (m)	**2564**	**2569**	**4611**	**4602**
Maximum top rope length on drum (m) (total length - 120 m)	**2444**	**2449**	**4491**	**4482**
Maximum number of rope layers on drum (Max = 5, Min = 3)	**4**	**4**	**5**	**5**
Rope tread pressure on drum and sheave (MPa) P_tread = 2*F_max/(d_rope*D_drum) (Max = 3.5)	**3.46**	**4.22**	**3.63**	**3.57**
Effective conveyance empty weight for top ropes (kN)	**622.3**	**866.3**	**271.2**	**311.2**
for winder drive power calculations (tonnes)	**63.44**	**88.31**	**27.64**	**31.73**
Effective payload for the top ropes (kN)	**418.9**	**435.6**	**387.4**	**311.2**
for winder drive power calculations (tonnes)	**42.71**	**44.40**	**39.49**	**31.73**
Inertia per single drum (with 2 drum compartments) $1422.1 * D\_drum^{3.5795} * Drum\_comp\_width$ (kg.m^2) rounded to nearest 1000	**4712000**	**4919000**	**8746000**	**8092000**
Inertia per single head sheave $112 * D\_sheave^{3.2}$ (kg.m^2) rounded to nearest 100	**97800**	**101600**	**140700**	**131300**
Inertia per winder motor (kg.m^2)	50000	50000	75000	60000
Maximum out of balance mass (tonnes)	**138.46**	**161.32**	**199.57**	**180.24**
Number of winder motors	2	2	2	2
Total combined force ventilated RMS motor rating (kW)	20711	16642	25939	18960
Force ventilated RMS rating per motor (kW)	**10355.5**	**8321.0**	**12969.5**	**9480.0**
Total combined peak motor rating (kW)	42835	49213	49487	45505
Peak rating per motor (kW)	**21417.5**	**24606.5**	**24743.5**	**22752.5**
Maximum motor and drum speed (rpm) (rope speed = 19 m/s, radius = (D_drum + d_rope)/2	**43.4**	**42.8**	**38.7**	**39.6**

Additional information on drum layers :

Top rope on 1st layer (m)	**612**	**610**	**885**	**885**
Top rope on 2nd layer (m)	**620**	**619**	**896**	**896**
Top rope on 3rd layer (m)	**629**	**627**	**906**	**906**
Top rope on 4th layer (m)	**638**	**636**	**917**	**917**
Top rope on 5th layer (m)	**646**	**645**	**927**	**928**
Top rope on 6th layer (m)	**655**	**653**	**938**	**938**