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Optimising the Warman® WBH® pump design

Introduction

The fundamental design brief for the Warman® WBH® slurry pump range was that it must be better than the Warman® AH® pump range in terms of performance and configuration. All with a lower Total Ownership Cost.

The AH® pump series was developed over many years, with new models and duty specific components added as mining demands for higher flows, higher heads (AH® pumps were originally designed for maximum of 35m), increased efficiency and longer wear life were specified across all four of the main duty categories. The AH® pumps were largely developed using 2-D design methods based on simple ratios and consequently do not form a consistent range as ratios varied across the range and the flow step between the Best Efficiency Points (BEP) of each of the models varied. To improve wear life, one design methodology is to make the pump larger and 'slower-running', with heavier section thickness in the assumed highest wear regions. However, this does not always deliver better wear life, lower Total Ownership Cost or an overall optimised design.

The incremental development of a wide range of product upgrades and improvements to the AH® pump consequently led to complicated configuration rules, often requiring improved materials to achieve the expected wear life. Product upgrades typically were targeted at one parameter such as efficiency, but not necessarily broadly at say efficiency and wear or efficiency with impeller backvanes to assist shaft sealing.

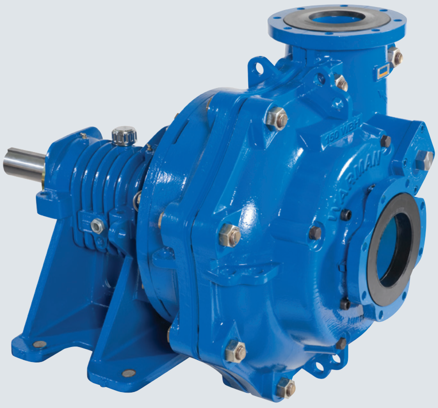
The main opportunities for optimising the design of the WBH® pump against the existing AH® pump are listed in figure 2. Developing the WBH® pump in consideration of these opportunities, it was possible to improve and optimise all aspects of performance and wear in the one design using 3-D design methods, CAD and computational fluid dynamics (CFD). The component thicknesses of the WBH® pump were set at approximately the same as the AH® pump, albeit with more uniform thickness throughout. This new methodology greatly simplified the design and pump configuration. The result is one configuration that is applicable across all four main duty categories.

Specific speed and impeller diameter

The specific speed formula (Ns) for any pump is listed in figure 1 and applies at the pump's Best Efficiency Point (BEP). The higher a pump's specific speed, generally the higher its efficiency.

To provide the same head-flow coverage for both the AH® pump range and the WBH® pump range, the head and flow of the standard 5 vane AH® impellers at BEP was set as the hydraulic design point for the equivalent WBH® pump models. With head and flow set, this leaves the speed as the main parameter to alter (increase) the specific speed.

The specific speeds of the various AH® pump models varies considerably from model to model, without a consistent trend. The AH® pump models for 100 mm discharge and larger are in the Ns range of 1,300 to 1,500 (US units).



Warman® WBH® slurry pump

Figure 1. Relevant pump formulae

Specific Speed (defined at BEP):

$Ns = (n*\sqrt{Q})/H^{3/4}$
where n = speed; Q = flow; H = head

Impeller Tangential Velocity:

$U = (2*\pi*r*n)/60$
where n = speed; r = radius

Euler's Pump Equation:

$gH = \eta_{HY}(UV_\theta)$

where g = gravity; H = head; η_{HY} = hydraulic efficiency; U = tangential velocity at impeller radius r; V_θ = component of absolute fluid velocity in tangential direction at impeller radius r

Euler's Head at zero flow:

$He \cong U_2/2g$

where U_2 = tangential velocity at impeller outer periphery

Wear Rate:

$W \propto C*v^3$
where C = material / solids parameter; v = local velocity

Figure 2. Opportunities for optimising the WBH® pump range compared to the AH® pump range

Increase the Specific Speed in some models by reducing the impeller diameter and increasing the pump speed for –

- Improved pump efficiency.
- Reduced pump size and mass to provide a more competitive offering.
- Improve upon poor performance of some AH® pump models.
- More consistent and reliable performance across the WBH® pump range.

Develop new Warman® WRT® adjustable throatbush and impeller combination for –

- Reduced impeller-inlet wear and streamlined impeller outlet flow into the volute.
- Improved NPSH required characteristic together with improved pump efficiency in the same design impeller.
- Full 3-D design using CAD modelling and Computational Fluid Dynamics (CFD) for streamlined flows to achieve lower wear rates and more even wear patterns throughout the pump, over a wide range of flows.

Lower Total Ownership costs due to -

- Longer wear life and lower overall energy consumption for the duration of the pumps life.
- Standardised construction and simple configuration with fewer duty specific parts and less mismatch of impeller and volute.
- Improved maintainability.
- Impeller-throatbush gap is adjustable during operation, thereby avoiding production downtime.

Table 1. Comparison of efficiency and speed for WBH® and AH® pumps

WBH® pump model	AH® pump model	Approx. increase in Efficiency at BEP of WBH® pump compared to AH® pump (percentage points)	Approximate Speed ratio for WBH® pump to achieve same BEP Flow and Head as AH® pump model
25	1.5/1	0	0.93
40	2/1.5	+5	0.95
50	3/2	0	1.00
75	4/3	+5	0.88
100	6/4	+8	1.04
150	8/6	+7	1.10
200	10/8	+8	1.18
250	12/10	0	1.13
300	14/12	+3	1.25

The specific speeds of the WBH® pump, on the other hand, form a more consistent trend increasing from the smallest model to the largest. In contrast to the AH® pump, the WBH® pump models from 100 mm discharge and larger are in the Ns range of 1,500 to 1,800 (US units). The efficiency improvement of the WBH® pump due to the increase in specific speed is shown in table 1 for each model for standard impellers with back and front vanes. The sample case studies in table 2 show significant energy savings as a result of these improved WBH® pump efficiencies.

The theoretical (Euler) head of a pump depends on velocities as shown in figure 1. To achieve the specified head, it is therefore a matter of maintaining the tangential velocity (U) by selecting an impeller outside diameter and adjusting the speed, with smaller diameters requiring a higher speed. The higher speed increases the pump specific speed and its best efficiency.

The approximate speed ratio for the WBH® pump models are shown in table 1.

Considering that the WBH® pump and AH® pump models are designed with the same head and flow at best efficiency point, and that the equivalent models also have approximately the same passage widths and volute sectional areas (the maximum particle passing size is approximately the same), consequently the internal velocities (V_θ) and velocity patterns will be similar between the two ranges. Hence, whilst the speed may be different between the equivalent models, the impeller tangential and the internal flow velocities will be of similar value and consequently the head developed will be the same according to Euler's equation.

Figure 3. CFD prediction for 8/6 AH® pump showing similar eye wear for two different diameter impellers at 132 L/s and 19.3 m

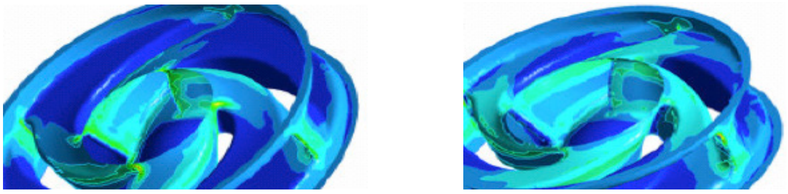


Fig. 3a. Large Diameter at 650 r/min

Fig. 3b. Smaller diameter at 810 r/min (1.25 times speed of larger)

Warman® WRT® Impeller and Throatbush Combination

The initial focus for the application of the WRT® impeller and throatbush combination was the impeller intake or eye region, as this is the region where the flow is turned from an axial velocity in the intake pipe to the radial velocity through the impeller. Consequently, the eye region normally has the highest wear, which in the worst cases, can lead to a significant reduction in the pump's head and efficiency.

The basic design of the WBH® impeller inlet was streamlined to turn the flow more gradually and 4 vanes were employed. The wear at the impeller eye was modelled and analysed using CFD, which was then compared to the field wear results. Good correlation was obtained, which underpinned the use of CFD as a design tool for optimising the WBH® impeller inlet geometry and its overall hydraulic design.

During the initial design phase of the WBH® pump, CFD was used to evaluate the wear in the eye region on a 'large' diameter and a 'small' diameter impeller for the 8/6 AH® pump. The impeller designs were aligned as far as possible, with the outside diameter being the main difference. The resulting wear rate and patterns were quite similar despite the speed difference ratio of 1.25, as shown in figure 3 (CFD depictions using the same colour scale for wear intensity). This result aligns with expectations, given that the velocities are similar between the two impellers (as per the Euler Equation and flow areas being similar) and that the wear is proportional to the velocity cubed (see table 1). Therefore evaluating wear based on pump speed alone can lead to an incorrect conclusion.

Further into the detailed design phase of the WBH® pump, CFD was used to evaluate wear intensity at the impeller eye by comparing the 8/6 AH® pump and the 150 WBH® pump for heavy duty at approximately 70% of BEP flow and assuming that the head and efficiency ratios were the same for both pumps. The CFD wear prediction is shown in figure 4.

The wear intensity scale was set to 1.0 at the highest wear point on the 8/6 AH® pump. Using the same scale for the 150 WBH® pump showed wear intensities less than 50% of those for the 8/6 AH® pump and the wear intensity was more evenly distributed. More even wear intensity should lead to more even wear overall and consequently less change to the vane geometry with less overall effect on performance over time.

Comparison of worn WBH® impellers to worn standard 5 vane AH® impellers typically showed less gouging wear on the WBH® impeller shrouds and less wear on the WBH® impeller pumping vanes. More even impeller wear typically results in less performance degradation over time. Wear life of the WRT® impeller is also typically longer than the five vane standard impeller and an increase of 50% in wear life is not uncommon.

The WRT® technology was also applied to the WBH® impeller discharge in the form of small vanelets that assist in reducing the wear caused by the impeller outflow and the recirculating flow around the impeller periphery. The vanelets assist to reduce the wear at the main pumping vane outlet as well as streamline the flow into and around the volute.

Figure 4. Wear intensity comparison of 8/6 AH® pump and 150 WBH® pump for heavy duty at 127 L/s and 45 m

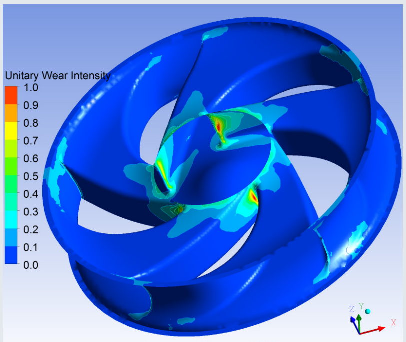


Fig. 4a. 5 vane 8/6 F6147 AH® impeller at 1,000 rpm and 70% BEP

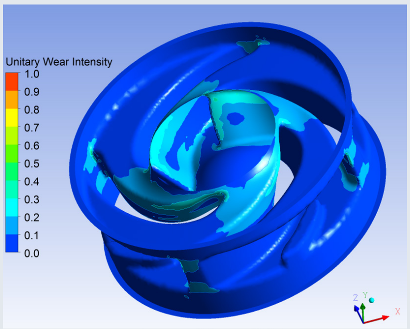


Fig. 4b. 4 vane 150 RCBH150145 WBH® impeller at 1,140 rpm and 72% BEP

The use of CFD as a design tool to optimise the hydraulic design of the WBH® pump also resulted in the pump having an improved internal hydraulic efficiency (i.e. less internal losses due to turbulence), hence more of the driving energy is delivered as flow and head. Lower internal turbulence results in smoother wear patterns over a wide flow range. Consequently, unlike the AH® there is less need to apply the WBH® pump at 75% to 80% of best efficiency flow to achieve optimal wear rates.

Performance comparison

A typical comparison of water performance between the AH® pump and WBH® pump is shown in figure 5. The head-flow characteristic and the BEP flow are approximately the same by design even though the pump speeds are different. The graph highlights the efficiency gain of the WBH® pump across a wide flow-range.

The WBH® pump typically shows even wear and combined with regular throatbush adjustment, the speed and power remain steady with time, indicating that the pump efficiency reduces by only a small amount with time.

The photos of the worn throatbushes (figures 6a & 6b) show the smoother wear of the WBH® pump compared to the 4/3 AH® pump, which was very badly gouged at only one third the life of the 75 WBH® pump (the 4/3 AH® pump was replaced with the WBH® pump). The regular throatbush adjustment of the WBH® pump has assisted the extension of throatbush life.

Comparing field results of the WBH® pump against the equivalent AH® pump (operating at the same duty) shows the following:

- The WBH® pump wear life was on average 1.65 times that of the AH® pump. Maximum life of the WBH® pump was 3.2 times that of the AH® pump. These wear life extensions correlate well with the CFD predictions obtained during the design phase.
- The power draw of the WBH® pump was on average 0.89 times that of the AH® pump. The minimum power draw for the WBH® pump was 0.8 times that of the AH® pump.
- The capital cost of a 200 WBH® pump was justified on the basis of its wear life increase alone.
- Trial of a 75 WBH® pump showed a payback of 0.8 years based on cost of spare parts and energy alone.

Total Ownership Cost (TOC)

The WBH® pump design includes a range of improved productivity, maintenance and safety benefits (as outlined in the WBH® product brochure), all of which contribute to lower Total Ownership Cost compared to the equivalent AH® pumps.

Field results for the same duty show that the WBH® pump consistently delivers longer wear life and reduced power when compared directly to the AH® pump, even though the speed of the WBH® pump in some cases is higher than the AH® pump for the same duty. These observations validate the calculations and predictions which underpin the development of the hydraulic design of the WBH® pump

The full TOC model includes: capital, energy, maintenance, service water, inventory, availability and overheads. For heavier duties, the main factors over a 5-year period reduce capital and spares plus maintenance and energy costs. Table 3 shows three cases of potential cost reductions for the WBH® pump when compared to the cost of the AH® pump (taken as 100 arbitrary units). Each of the cases show a substantial benefit by changing to a WBH® pump. The range of TOC reduction for these WBH® pump cases varies from 3.5% to 19%. These are arbitrary units but the breakdown between capital cost, spares cost and energy consumption are typical for a 5 year interval.

Figure 5. Clear water performance curve comparison

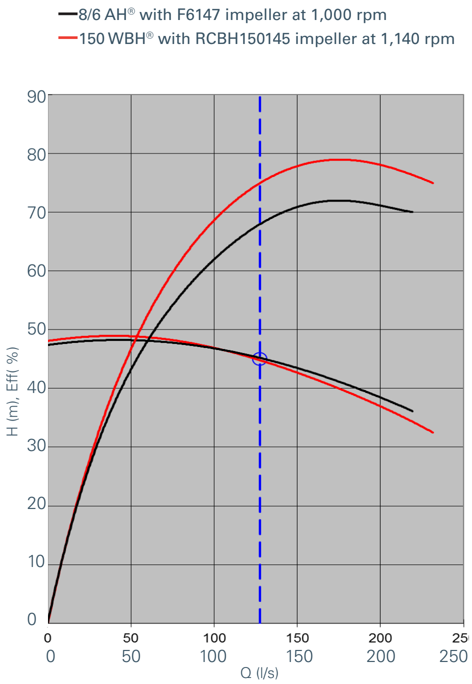


Figure 6. Wear comparisons demonstrating the benefit of WBH® throatbush adjustment feature

Figure 6a. 4/3 AH® throatbush at 2,200 hours (no adjustment)

Figure 6b. 75 WBH® throatbush which replaced the 4/3 AH® throatbush at 6,767 hrs with regular adjustments

Summary

The design optimisation of the Warman® WBH® pump was assisted by accounting for the opportunities available upon studying the Warman® AH® pump. Setting the plan early for Specific Speed lead to a more robust and energy efficient design applicable across all four duty categories using basically one configuration.

Reducing the impeller diameter (and increasing the speed) of some WBH® pump models has improved their overall performance. The WRT® impeller and throatbush combination and the adjustable throatbush have reduced the impeller eye wear to an extent where impeller and throatbush wear life is no longer the limiting factor as has been the case for the AH® pump range.

The fundamental theory, CFD analysis and optimisation together with the field-test results of smaller diameter WBH® impellers running faster, have consistently pointed to improved results compared to the standard AH® pump.

The advanced features, improved wear life and improved energy efficiency of the WBH® pump in comparison to the standard AH® pump translate to real-world Total Ownership Cost improvements for pump operators.

Figure 7. Wear results on the WBH® impeller and volute

Figure 7a. Even wear on WBH® impeller

Figure 7b. Even wear on WBH® volute

Table 2. Measured power consumption improvements for WBH® pumps replacing AH® pumps

Pump Application	Pump Size	Flow L/s	TDH m	CW %	SG t/m³	Pump N rpm	%BEP	Pump Eff %	Pump kW	Power Savings kW
Mill Cyclone Feed Pump	8/6 E-AH® 150 RC-WBH®	125.0 125.0	11.4 11.4	57.0 57.0	1.81 1.81	580 765	120 120	70 76	36.1 33.2	0.0 2.9
Coal Heavy Media Transfer	8/6 E-AHE® 150 RC-WBH®	147.0 147.0	26.2 26.2	64.0 64.0	1.67 1.67	795 929	102 102	73 78	89.0 80.2	0.0 8.8
Mill Discharge	8/6 E-AH® 150 RC-WBH®	86.0 86.0	21.4 21.4	58.0 58.0	1.66 1.66	685 785	66 70	65 75	49.8 43.1	0.0 6.7
Residue Pump	4/3 C-AH® 75 PCY-WBH®	30.3 30.3	52.3 52.3	20.0 20.0	1.15 1.15	2250 2004	53 60	60 66	29.8 27.1	0.0 2.7
Primary Sand Cyclone Feed	8/6 E-AH® 150 RC-WBH®	100.0 100.0	32.0 32.0	14.5 14.5	1.10 1.10	810 955	63 70	65 73	53.1 47.3	0.0 5.8
Primary Sand Cyclone Feed	8/6 E-AH® 150 RC-WBH®	92.0 92.0	25.0 25.0	30.0 30.0	1.23 1.23	740 876	66 77	65 74	42.7 37.5	0.0 5.2

Table 3. WBH® Total Ownership Cost model under varying scenarios over 5 years

Major cost	AH® TOC	WBH® Case1		WBH® Case2		WBH® Case3	
		change	TOC	change	TOC	change	TOC
Capital	10	1.10	11.0	1.00	10.0	0.90	9.0
Spares/Maintenance	30	0.95	28.5	0.85	25.5	0.70	21.0
Energy	60	0.95	57.0	0.89	53.5	0.85	51.0
TOC (units)	100		96.5		89.0		81.0

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