Strategic Refurbishment Program for Reactor Coolant Pumps and Motors (Ref: WB-P&M-16-198)

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Summary

Most PWR Reactor Coolant Pumps and Motors (RCP&M's) have reached minimum 25 years of operation. Seals and motors heavy maintenance is performed periodically along the prescriptions of the Westinghouse User Manual and further Technical Bulletins. As such, they are well prepared to meet the Plant Life Extension objectives of the Utilities. User Manuals are less prescriptive for the RCP internals. In Europe, most RCP internals have undergone one overhaul over their lifetime within a hot workshop. Is that sufficient to meet the Utilities Plant Life Extension (PLE) objectives? This paper opens up a discussion as to the need to plan for a next structured refurbishment program on basis of a qualitative analysis of the known issues suspected to re-occur after their first major overhaul.

Westinghouse proposes a solution to cure these problems and suggests a cooperative and comprehensive reactor coolant pump and motor asset management program consistent with the Utilities PLE objectives.

1. INTRODUCTION

In 2017, there are more than 440 Nuclear Power Plants operating over the world and about 150 in Western Europe. 50% are based on Westinghouse technology, the PWR design. A key component of the PWR primary loop is the Reactor Coolant Pump (RCP). Most plants are equiped with 3 or 4 Reactor Coolant Pumps, one per loop. This is a single stage vertical pump used to circulate water through the core and transfer heat to the secondary system. About 600 Reactor Coolant Pumps manufactured by Westinghouse or its licensees are running over the world and 240 in Western Europe. These pumps are driven by large vertical electrical motors. Mechanical seals, located between the pump and the motor, are employed to isolate the process fluid within designated system boundaries.

Westinghouse users manuals provide instructions for the periodic maintenance of the seals and the motors, from yearly routine to more in depth maintenance / refurbishment (for example, every 10 cycles or so for the motor). For the pump, maintenance, instructions concern prevention or mitigation of pressure boundary leakage, vibration montoring and evaluation, balancing, alignment, studs tensioning checks. Technical publications such as the Westinghouse Technical Bulletins (TB-91-04, TB-96-02, TB-04-5 et al) complement these instructions to reflect the acquired operating experience.

On the other hand, such instructions do not exist for the Pump internals themselves. The Pump internals are made of the rotating components – shaft, impeller, coupling, bearing – and the static components – thermal barrier, heat exchanger, N°1 seal housing, diffuser (see figures 1 & 2). The absence of periodic maintenance recommendations for the pump internals is because of the robustness of the original design of the constitutive parts and that none of them were considered to be wearing parts, planned to be inspected and replaced periodically.

The utilities, as operators, have been proactive though and have inspected pump internals as a result of a combination of factors such as sound industrial oversight, questions from their local Safety Authorities, prevention plan recommended by the Original Equipment Manufacturers (OEM's) or non-typical behaviour of the pump.

The most common Westinghouse RCP models in Western Europe are the 93D and 100D (57% are 93D and 40% are 100D). All PWR Plants in Western Europe with 93D model RCP's have already performed the inspection and refurbishment of their pump internals at least once, generally after 15 to 25 years of operation. Similarly all Westinghouse 100D model RCP's have been refurbished once or are programed to be refurbished within the 10 years to come. As such, the corresponding Utilities, supported by the OEM's and Westinghouse in particular, are quite ahead of the movement, leading the initiative since the late nineties and accumulating unique Pump internals maintenance expertise. In comparison there are RCP's in the US which have been running for more than 40 years without major refurbishment.

An initiative is led now by the Pressurized Water Reactor Owners Group (PWROG) to gather all of this accumulated experience and lessons learned from the main OEM's in anticipation of the next steps, i.e. safe continued operation until design plant life time or Plant Life Extension (PLE) – next 10 years license renewal or beyond, Long Term Operation (LTO).

Most of our Western Europe PWR plants are averaging 25 to 35 years operational life time. In order to maintain safe and reliable Plants operation and in view of the PLE objectives, while waiting for the results of the PWROG initiative, it is now worth questioning and anticipating the possible necessity for these pumps internals to be inspected and refurbished once more, and to plan for it.

2. SEALS, MOTOR AND PUMP REFURBISHMENT PROGRAMS

As explained, mechanical Seals are subject to periodic maintenance including replacement of usual wearing parts. Safe and reliable pursued operation of the Plants will be guaranteed by the implementation of existing maintenance instructions. New available Westinghouse products such as the Safe Shutdown Seal "SHIELD®" – to respond to Station Blackout or Fire Scenarios – or the 12 years lifetime High Temperature O-rings extending the maintenance intervals enable to enhance safety and Plant economics. SHIELD® will be installed on more than one hundred pumps in USA by the end of 2016. SHIELD® was first time installed in Europe on 93D type pumps in the spring of 2016. Improved seals design, being currently developed and tested by Westinghouse, will further enhance seals reliability and operability. We would like to refer to the article "Developments in Reactor Coolant Pump Seal Enhancements Including Post-Fukushima Solutions" presented in another session of the TopSafe 2017, for further details relative to the Westinghouse seals program.

As for seals, large RCP Motor overhaul is already routinely programmed by the Utilities along the periodicity recommended by Westinghouse in our User's Manuals and Technical Bulletins. In particular, Westinghouse Technical Bulletin TB-04-5 outlines the W RCP Motor inspection and refurbishment program after 9-12 cycles). This program goes from total disassembly, detailed part per part inspection, systematic wearing parts replacement and non-systematic parts replacement as necessary, restoration to original interface tolerances as required, all electrical and mechanical testing, re-assembly and final no load testing. This is performed since 15 years in our "hot" workshops at Waltz Mill – USA (even 30 years with our alliance partner EMD in their Cheswick – USA workshop) and since 2010 in Nivelles – BE. This program is complemented by the possible installation of several RCP Motor upgrades (Note 1). In addition, stator winding failure risks – well described in INPO Topical Report TR 5-50,– is mitigated by the decision of almost all European Utilities to programmatically replace their stators, as part of the third (10) cycles refurbishment. As such, the RCP Motors are cautiously monitored and naturally prepared to meet the operational challenges and safety requirements resulting from continued operation and Plant Life Extension.

In absence of routine detailed maintenance plan as it exists for the seals and the motors, the possible next inspection and refurbishment of Reactor Coolant Pumps with regard to Continued Operation and PLE objectives, would need to be developed. Regulatory requirements, previous inspection findings and their possible recurrence, current operating behavior / trending, known parent design issues, anticipated further wearing or degradation mechanisms, operating and safety risks and consequences shall justify and drive the elaboration of such next refurbishment plan.

By considering aspects such as availability of spares, outage schedule impact, budgets and investments planning, etc… Westinghouse can propose a comprehensive asset management program and working in partnership with the Utilities, would take commitments for these components relative to Continued Operation or PLE objectives.

Original design lifetime is generally 40 years for the RCP's.

Operating these components beyond this limit requires that an analysis be performed to determine if there is still sufficient margin relative to fatigue limits. This can be done in comparing the actual transients and type versus what was originally assumed for the design. As the values considered for the design are conservative, this analysis generally reveals that the RCP internals are not structurally limited by fatigue stress considerations.

Beyond this analysis, a lot of other aspects influencing Continued Operation or PLE objectives have to be considered and they are not necessarily leading to clear quantified conclusions as for the fatigue analysis. Their impact needs to be evaluated qualitatively on basis of past experience, engineering judgment, relevant past studies results, etc…

Figures 1 & 2 show RCP internals for the most common RCP models in Europe, typically Westinghouse 93D (57%) and 100D (40%) RCP design models.

Some known issues affecting these pumps have been gathered in Table 1. We deliberately opted to focus on the rotating parts and on issues that are expected to re-occur in the future despite the mitigation actions taken during the first pump refurbishment. The objective is to evaluate these issues relative to their possible impact on Continued Operation or PLE objectives. This table is far from exhaustive but enough to trigger the necessary questioning approach relative to the need for a future structured maintenance plan. This table, as produced, is more a tool to be used in discussions with the Utilities than a deterministic decision making tool.

For example, from the table, one can reasonably assume that shaft cracking under the thermal sleeve will re-occur because the problem was mitigated but not cured. Loose impeller – essentially for 100D models but now suspected as well on 93D model – is quite probable. Cracking and looseness, by nature worrisome and sensitive – even more in the post Fukushima and public skepticism context – would by themselves deserve some form of remediation. Due to increasing vibration amplitudes, the destructive impact of a loose impeller on its direct environment could potentially materialize itself into labyrinths ID ovalization, bearing degradation and resulting hydraulic gaps enlargement as observed during recent refurbishments.

When combined with other known risks such as Thermal Barrier flange deformation and possible leaks at the interface with the casing or impeller vanes degradation, it is not unreasonable to foresee that although there is no direct safety impact, this combination of degradation factors would require an intervention within the projected life span of the RCP in case of PLE.

To prevent significant operational impact and costs in case of spurious degradation, such quite probable intervention would deserve to be planned such that the next refurbishment of the RCP internals would be performed within a timeframe which would align with the Utilities outages plan, budget plan, etc… and the estimate optimum common timing at which the expected issues would need to be addressed.

On average, Plants in Western Europe with 93D pumps are 30 to 35 years old and with 100D pumps, a few years younger. So considering a first refurbishment in the 2000-2005 period, the next refurbishment of the 93D pumps would as necessary, optimally be programmed starting 2020 and the 100D pumps a few years later. Some European Utilities have decided though to anticipate the 100D's refurbishment program. This rough schedule would provide Utilities the ability to properly program their budgets, procurement process, specifications, etc…

3. CONCLUSION

RCP seals and motors maintenance is well prescribed within the Westinghouse Users Manuals, further complemented by other subsequent technical publications. As such, these components are prepared on a continuous basis to meet the Continued Operation and PLE objectives. To extend the components lifetime, an analysis comparing the design assumptions versus the actual operating conditions, needs to be performed to demonstrate that there is still sufficient margin relative to fatigue limits.

Such detailed prescriptions do not exist for the RCP internals. But on basis of past refurbishment results, operating behavior observation, aging issues anticipation, they can be developed.

Analyzing past inspection and refurbishment / repair data, current operating pumps operational behavior and anticipating issues by comparison with parent designs lessons learned, the need to foresee a (next) inspection / refurbishment of the Western Europe 93D or 100D pumps needs to be investigated with regard to known existing or re-occuring issues and their impact on PLE objectives. This inspection / refurbishment period could start around 2020, for the pumps which have been inspected / refurbished once in the 2000 – 2005 time frame. The refurbishment program including spares components definition would inspire itself from typical issues tables such as the one below.

Westinghouse is deeply involved in such refurbishment programs, has solutions for the subsisting issues affecting the RCP internals and is willing on basis of their design and maintenance experience, as OEM, to partner with the Utilities to develop their RCP's and Motors asset management program in anticipation of their Plant Life Extension initiatives.

Note

RCP Motor upgrades: Oil Spillage Protection System (OSPS), Continuous Oil Level Monitoring, Oil Lift System reinforcement – Pump, piping, flanges, supports, Lower Cooling Coil Upgrade, Dynamic Port Upgrade, Lower Guide Bearing Modification, Lower bearing labyrinth Seal improvement, Remote Visual Inspection, Additional RTD's installation, etc…

REFERENCES

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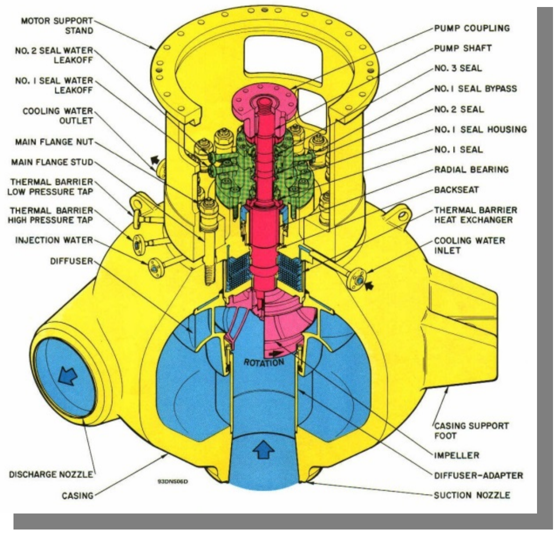

Fig 1 - Westinghouse Model 93D RC Pump

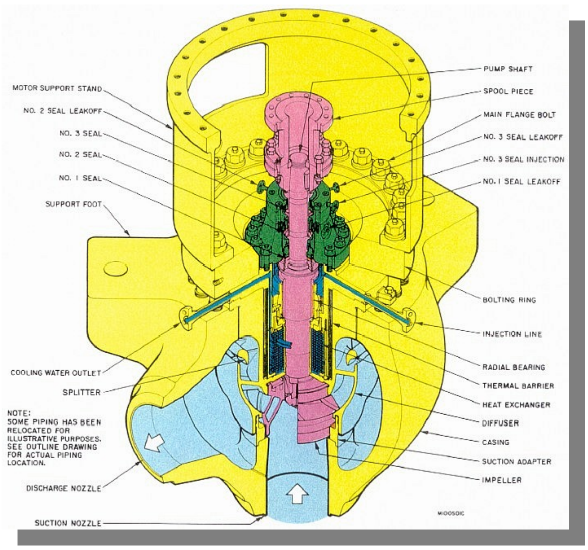

Fig 2 - Westinghouse Model 100D RC Pump

#	Pump Model	Issue	Symptoms	Risks	Probable cause	possible remedy	Observed when	Probability of risk occurrence	Operational impact	Timing for occurrence from last refurbishment	Consequence on direct environment	Is it wise pursuing PLE w/o refurbishment / repair?	Comments
1	93D / 100D	Shaft cracking on / under the thermal sleeve	Nothing truly noticeable, until vibrations increase close to catastrophic failure	Shaft integrity / Direct environment degradation	Thermal cycling / fatigue	Shot peening / thicker thermal sleeve (93D) 3 fit sleeve (100D)	R	H	Y	2	M	N	Shot peening / thicker thermal sleeve will not prevent cracking on 93D 3 fit sleeve has proven to prevent cracking on 100D
2	93D / 100D	Crack in shaft key housing	Nothing truly noticeable except maybe balancing difficulties, vibration crisis	Loose key/crack propagation	heat up / cool down transients, temporary loose fit between impeller and shaft	Cracks elimination if at surface, shaft replacement, key housing redesign,	R	M	Y	2	L	Y / N	1st refurbishment has not definitely solved issue on 93D. Shaft end redesign solves it for 100D
3	93D / 100D	Damaged backseat on shaft & thermal barrier	Back seat leakage during outages	Excessive water waste production, possibly lost outage time	Foreign object, mishandling during discoupling	Reshape the surface during refurbishment	R / O	H	N	2	L	Y	
4	100D	Loose impeller	Difficulties to balance, erratic vibrations	Vibrations/ damage on impeller and shaft tapered fit / Direct environment degradation	insufficient fit / advance between the impeller and shaft or locknut not seating on impeller	Refurbishment incl'g matching cones reshaping, fit redesign, …	O / P	M	Y	3	H	N	Hollow shaft solves the issuefor 100D Start observing some strange behavior on isolated sites with 93D.
5	93D	Degraded impeller vanes	Nothing truly noticeable	Impeller integrity / hydraulic performance - Loose part	Cavitation / erosion	Repair if possible / replace impeller	R	L	Y	2	L	Y / N	

Table 1 – Known degradation phenomena for 93D & 100D RCP internals (rotating components)

Legend	
Y / N	Yes / No
0 / L / M/ H	Low / Medium / High
Timing	0-Will not occur
	1-Short term (0 to 10 years)
	2-Mean term (10 to 20 years)
	3-Long term (> 20 years)
Observed	R-1st pump refurbishment
	O-During operation
	P-Parent design issue
	A-Anticipated