ENCLOSURE 4

ALSTOM LOW PRESSURE TURBINE ROTOR REPLACEMENT REPORT
NON-PROPRIETARY VERSION

San Onofre Nuclear Generating Station
Units 2 and 3

ALSTOM

SAN ONOFRE 2 & 3

REPLACEMENT LP ROTORS

EDITED VERSION - PROPRIETARY INFORMATION REMOVED

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SAN ONOFRE 2 & 3 - REPLACEMENT LOW PRESSURE (LP) ROTORS

1. Existing LP Rotors

The existing San Onofre 2 & 3 LP rotors are double flow with 8 stages in each flow, and the rotors are of shrunk-on disc construction, see figure 1. Stages 1 - 6 moving blades are retained by "straddle" roots, and the L-1 and L-0 stages are retained by axial entry root fastenings. The L-0 blade is 45" long.

It is now well known within the power industry that rotors of shrunk-on disc construction are susceptible to stress corrosion cracking (SCC) at areas of high surface stress, such as blade root fixings, steam balance holes, and disc bores. SCC has been observed on the existing rotors after about 80,000 operating hours. Cracks have initiated in areas of stress concentration at the straddle root fixings and the steam balance holes of the discs of the early wet stages (stages 4, 5 and 6).

2. Replacement LP Rotors

The replacement LP rotors are of welded construction with the stages arranged in an "Optiflow" configuration, see figure 2. The first four stages are single flow, enabling increased blade heights and reduced leakage to achieve optimum performance. After the first four stages the flow splits and continues through a further four stages arranged in conventional double flow.

Stages 1 - 6 moving blades are attached to the rotor using multi-finger pinned root fastenings and have torsion mounted integral shrouds in line with ALSTOM standard practice, see figure 3. The long L-1 and L-0 blades are retained by axial entry root fastenings (straight for the L-1 and curved for the L-0). The L-0 blades, see figure 4, are provided with continuous blade-blade interconnection in the form of integral 'snubbers' to control non-harmonic vibration, such as the buffeting conditions which occur at high back pressures. The L-0 blade is 47.25" long (1200 mm).

The welded rotor consists of five relatively small forgings in 3%NiCrMoV welded together to form a single rotor. The use of a welded rotor gives the following benefits:

- Elimination of shrink fits and keyways
- Low levels of tangential stress
- Use of lower strength material with consequent improved SCC resistance
- Relatively small forgings, allowing high resolution during ultrasonic inspection

3. Welded Rotor Experience

ALSTOM is the largest single supplier of nuclear steam turbines in the world, having supplied more than 20% of the world market. The entire French nuclear program uses exclusively ALSTOM steam turbines, up to and including the largest half speed units in the world - four 1530 MW, 1500 r/min units at Chooz B and Civaux. ALSTOM is the leading exporter of nuclear steam turbines into China and has supplied two 985 MW, 3000 rev/min units for Daya Bay in China with a further two units on order for Ling Ao. These turbines are some of the largest full speed nuclear units in the world.

The replacement LP turbine rotors for San Onofre Units 2 & 3 utilize the well proven ALSTOM welded rotor technology. This technology has been used since the 1950's in fossil units and has been applied in operational nuclear turbines since 1981. To date, 119 welded LP rotors have been supplied for nuclear steam turbines operating with pressurized water reactor (PWR) steam conditions. These turbines include the 1530 MW units at Chooz B and Civaux in France, together with the recent nuclear LP retrofits at Tihange and Doel in Belgium.

The largest welded LP rotors supplied by ALSTOM are those in the Chooz B and Civaux units, which weigh 365,000 lbs when fully bladed. The rotor length is 39 feet 3 inches, and the last stage blades are 57 inches long with a tip diameter of 18 feet 4 inches. For comparison, the replacement San Onofre LP rotors weigh 312,000 lbs and 35 feet 5.7 inches long with last stage blades 47.25 inches long and a tip diameter of 15 feet 2.5 inches.

Some of these units have accumulated more than 100,000 operating hours (see table 1), and SCC has never been found on any of these nuclear steam turbine welded rotors. The 6 replacement LP rotors for San Onofre take advantage of this extensive and successful operating experience.

Optiflow LP turbines have been widely applied by ALSTOM over many years (see table 2) and extensive operating experience has been accumulated with many of these units. In particular, the LP retrofit of the 2x500 MW PWR nuclear units at Tihange, Belgium uses optiflow LP turbines. In the USA, the 285 MW Dupont Chambers plant in New Jersey has an optiflow LP turbine.

4. Rotor Material Specification

Specified material composition and mechanical properties for the welded rotor forgings are given in the appended Table 3, together with a near equivalent ASTM grade for information.

Actual mechanical properties are provided in the appended Table 4, where it can be seen that all properties meet the specified requirements.

5. Rotor Inspections During Manufacture

It has been ALSTOM policy for many years to take delivery of forgings in the unbored condition from suppliers with a proven (qualified) manufacturing process, and it is a policy consistent with that of other original equipment manufacturers (OEMs), such as ASEA Brown Boveri. A qualified manufacturing process is one which is demonstrated to produce the required material properties, including tensile strength and fracture appearance transition temperature (FATT), throughout the volume of the forging. Qualification of a manufacturing process requires that a number of production forgings are bored to establish that the required properties are achieved in material removed from the forging centerline. Following qualification of a suppliers process, subsequent forgings are supplied in the unbored condition, the achievement of specified properties at sampling positions towards the periphery of the forging coupled with the close control of the qualified forging process guarantees that the required properties are obtained throughout the forging.

Modern rotor forgings are produced by leading edge technology steelmaking methods, utilizing optimized ingot designs which minimize segregation during the solidification process. Adequate discarding of ingot ends removes the segregated zones from the usable part of the ingot. The forging methods employed give full consolidation of the ingot and eliminate center-line porosity. This, together with uniform heat treatment, results in uniform mechanical properties and low ultrasonic attenuation characteristics. The ultrasonic test methods applied to large unbored forgings reliably detect defects which are well below the small sizes permitted by the Alstom non destructive testing (NDT) acceptance standard. It is, therefore, considered unnecessary to bore forgings to establish that they are free from unacceptable defects.

For the above reasons turbine manufacturers do not bore rotor forgings provided by qualified suppliers. In fact, it is not only unnecessary but is generally undesirable since an axial bore acts as a stress concentrating feature, increasing the stress at the center of the rotor by a factor of two compared to the unbored condition.

A brief background to the procurement of the individual forgings, and their inspection both at the forge masters works, and at the ALSTOM works during and after welding, is given below:

Material Composition: All forgings are of the same composition as shown in Table 3.

Heat treatment: Heat treatment of the forgings is carried out to a practice refined by ALSTOM. It includes a Preliminary Heat Treatment intended to refine the structure followed by a Quality Heat Treatment to further refine the structure for ultrasonic testing and to produce the required mechanical properties.

Typically, Preliminary Heat Treatment comprises normalizing from 850°C followed by tempering at about 650°C. For the Quality Heat Treatment, solution treatment is typically carried out at 850°C for about 15-20 hours, followed by water quenching.

A tempering treatment is subsequently carried out at ≥610°C for a time dependent on the forging size.

Micro structure: The 3%NiCrMoV forgings are fully bainitic and typical of the micro structure in monoblock rotors. Modern steelmaking practice for large rotor forgings results in low sulphur values (0.003% mean, 0.008% max) leading to fewer sulphide inclusions than are found in older forgings.

Mechanical properties: Properties are determined in several locations on each forging after completion of Quality Heat Treatment at the forge master. Test material removed from each forging in the region of the weld preparation zone after the Quality Heat Treatment then accompanies each forging through the post weld heat treatment (PWHT) at the ALSTOM works, when the mechanical properties and FATT are verified.

Weld repair: No weld repair by the forge master is permitted on the individual forgings.

NDT by forge master: 100% of the volume of each forging is examined using normal compression wave probes and angle compression wave probes per Alstom standards. In addition, blade attachment zones and the weld preparation areas are further examined using shear wave probes.

Weld technique and NDT

The root pass is carried out using the TIG process with the rotor forging stacked in the vertical position. Following the weld root pass, welds are 100% radiographed. After radiographic examination, and any repair of the weld, the rotor is set horizontal for completion of welding using the submerged arc process.

After completion of the welded joint, and after preliminary surface preparation, all welds are dye penetrant tested and subjected to 100% ultrasonic test (UT) prior to PWHT per Alstom standards.

After PWHT, each weld is subjected to 100% magnetic particle inspection (MPI) and 100% UT per Alstom standards following the required surface preparation.

After in works overspeed of the assembled rotor (20% for 5 minutes) all accessible areas of the rotor surfaces are subjected to MPI.

PWHT:

PWHT is carried out in a dedicated furnace, with the rotor in the vertical position, for about 20 hours at 620°C. Mechanical properties are then re-established on the test material accompanying each rotor through the PWHT. The properties given in Table 4 are those obtained after the PWHT

6. Rotor Stresses

The acceptability of the operating stress levels in the new rotors has been established by considering all potential failure mechanisms. The assessment of the integrity of the new rotors in respect of each potential failure mechanism is summarized below.

6.1 Tensile Strength

Ductile failure during overspeed is governed by the level of mean stress due to centrifugal loading on potentially critical sections of the rotor in relation to the yield strength of the rotor material. Local peak stresses in regions of stress concentration have no effect since they will relax completely as the bulk material approaches yield.

The margin between mean section stresses at normal operating speed and material yield strength are very large, so that a gross overspeed would be required to cause ductile failure of a rotor. Attainment of such a high overspeed is possible only in the event of multiple failures of components in the overspeed protection system, the probability of which is very low as demonstrated in the Missile Analysis Report.

6.2 Low Cycle Fatigue

The potential for repeated application of centrifugal and thermal loading during unit start-up and shut-down to cause low cycle fatigue cracking to initiate in regions of high stress associated with stress concentrating features has been investigated. Maximum and minimum local peak stresses at all significant stress concentrating features on the rotor have been calculated for an operating cycle, and the corresponding strain ranges have been compared with low cycle fatigue initiation data for the rotor steel assuming 500 operating cycles. For 500 cycles, the minimum factor of safety on strain is calculated to be 1.8 for the worst case location which is the blade root fastening at stage 8. This factor of safety on strain corresponds to 5,000 start-up and shut-down cycles which represents a factor of safety of 10 for start-up and shut-down cycles. This number of cycles is conservative in relation to the anticipated cyclic duty. It would be more realistic to assume based on SONGS historical information that the number of start-up and shut-down cycles for a 40 year turbine design life would be well below 500 cycles. Owing to the relatively low number of cycles, the margins against crack initiation are large and there is no risk of low cycle fatigue crack initiation in service.

6.3 High Cycle Fatigue

The potential for high cycle bending stresses due to shaft rotation to cause cracking has been investigated. High cycle stresses due to gravity bending, bearing misalignment and a pessimistically assumed degree of rotor coupling misalignment have been evaluated allowing for the effects of stress concentration in the fillet radii at changes in shaft section. For bearing misalignment, it was pessimistically assumed that any bearing could be unloaded by 50% of its smoothly aligned load. For coupling misalignment it was pessimistically assumed that the sum of periphery error and the coupling gap error is a maximum of 0.010". This combination represents an extremely conservative load case used for the high cycle fatigue calculation. The calculation demonstrated that the margin between the maximum high cycle fatigue bending stresses and the design fatigue limit of the rotor material in the most critical areas is 1.5 at the fillet radius of stages 4 and 8 discs. The design fatigue limit at these locations is only ± 6% of the tensile strength and itself incorporates a large additional margin of safety. Therefore there is no risk of high cycle fatigue crack initiation in service. Moreover, high cycle fatigue cracking is not considered to be a mechanism for missile generation.

6.4 Growth of Initial Forging Defects by Fatigue

The potential for repeated application of centrifugal and thermal loading during unit start-up and shut-down to cause pre-existing defects within the rotor forging to extend to a size which could cause brittle fracture has been investigated. Defect growth during 500 start-up shut-down cycles has been pessimistically assessed assuming initial defect sizes which are much larger than the maximum ultrasonic indication sizes permitted by the defect acceptance standard applied to the rotor forgings, and fatigue crack growth rates which are higher than the upper bound of the available data. The resulting fatigue extended defect sizes at end of service were compared to the minimum critical crack size for brittle fracture during overspeed assuming minimum expected material fracture toughness.

It is demonstrated that even for extremely conservative assumptions used for the calculation of failure probability, the ratio of minimum critical defect size to maximum fatigue extended defect size is 2.8 for the surface zone, and greater than 5 for the sub-surface zone. Therefore, the margins between maximum fatigue extended defect size and minimum critical defect size are large since the growth of defects in service is calculated to be very small and the minimum critical defect sizes are relatively large, as described in the Missile Analysis Report (see section 2.3.2.1 of Reference 1).

6.5 Stress Corrosion Cracking

Particular attention has been paid to the evaluation of the risk of fracture due to stress corrosion cracking (SCC), since as described in Section 1 of this report, SCC has occurred in the original rotors and is the reason for their replacement.

Stress corrosion crack initiation and growth testing by ALSTOM over the past 25 years has resulted in the accumulation of a considerable body of test data. More than 200 long term tests have been carried out on NiCrMoV rotor steel, over a range of yield strength levels from 650 - 1050 MPa (94 - 152 ksi) and a range of applied stresses from 20% to 100% of yield strength in pure steam and contaminated steam environments at 95°C. The results of these tests have shown that the threshold of applied stress to cause SCC increases markedly as yield strength decreases. Not only does the threshold ratio of applied stress to yield strength increase with decreasing yield strength, but the absolute value of threshold stress also increases. The effect of temperature on SCC threshold stress has been deduced on the basis of ALSTOM service experience of SCC, together with data published in the technical literature, which shows that the SCC threshold stress decreases with increasing temperature. Taken together, the laboratory data and service experience have enabled the dependency of SCC threshold stress on material yield strength and operating temperature to be established.

It follows therefore, that in order to maximize resistance to SCC the lowest yield strength consistent with other strength requirements of the rotor should be adopted and peak stresses in operation should be kept to as low a level as possible.

In the original rotors the operating stresses at the straddle root blade fastenings in the disc rims and at the steam pressure balance holes, where SCC was observed to be present as described in Section 1, have been calculated, and at each location the local peak stress is well above the threshold for SCC initiation at the relevant operating temperature and disc yield strength. This is due to the relatively high yield strength of the original discs, with values in the range , and the relatively high levels of calculated peak stress.

In the new rotors, the operating stresses at all locations are below the SCC threshold. The fundamental change which permits design below the SCC threshold is the selection of a welded rotor construction. The welded rotor forgings carry centrifugal load much more efficiently than a shrunk-on disc rotor, in which the central shaft takes no part in carrying the centrifugal load of the blades and the disc itself but increases the disc stresses due to the shrink fit. In consequence, the tangential stresses in the welded rotor are reduced to about half the level of the shrunk-on discs of the original rotors as illustrated for a typical stage in Figure 5. The reduction in stress level permits the specification of a significantly reduced yield strength without compromising normal design margins. The specified yield strength range of the forgings for the new rotors is , the reduction in yield strength relative to the original discs providing a significant increase in the SCC threshold of the new rotors.

The method of blade attachment has also been changed for the new rotors. Pinned roots are now used at all stages which originally had straddle roots, thus eliminating the higher stress concentrations associated with the small fillet radii in the straddle root profile. This, together with the lowering of general stresses associated with the welded rotor construction, minimization of the blade loadings and optimization of the detailed design of the root fixings, have all contributed to a significant reduction in local peak stresses relative to the original rotors.

Additionally, in the past the incidence of SCC of disc and rotor materials has often been linked to the presence of halide and sulfide contaminants in cutting oils and the use of anti-scuffing or anti-seize compounds containing molybdenum disulfide. ALSTOM now operates a clean build policy in which molybdenum and low melting point elements are completely eliminated from cutting fluids, lubricants, and anti-seize compounds, and in which the halide content of any cutting fluid or lubricant used on steam path components is limited to 200 ppm maximum.

For these reasons the new rotors are considered to be effectively immune from SCC in operation. However, the risk of SCC initiation and growth leading to fracture, of a rotor has been assessed probabilistically in the Missile Analysis Report.

7. Inspection Intervals

ALSTOM has very extensive operating experience with modern design LP rotors of welded construction with pinned root integral shroud blades. This operating experience has been fully considered in the development of the design for the new rotors leading to a high level of confidence that the new rotors will operate satisfactorily for long periods without the need for inspection or remedial action.

Risk of stress corrosion cracking is eliminated by the combination of low strength rotor material and careful design to ensure low stress levels.

The stage 1 - 6 blading is selected from the ALSTOM standard range and has well established vibration characteristics. To provide additional assurance, rotating vibration tests are being carried out on each stage of one LP rotor during the in-works balance and overspeed runs.

Six LP rotors of similar welded construction with identical L-1 and L-0 blades have already been in service for over 60,000 hours at Ulchin Power Station (Korea Nuclear 9 & 10) and these rotors will provide, in effect, a continuing test bed for the San Onofre design.

The Missile Analysis Report assumes ten years of operation between inspections of the LP rotors and demonstrates that the probability of failures occurring is in compliance with NRC safety regulations.

Other possible problem areas within the LP cylinders, such as erosion of tip seals, pressure faces, and joint faces, have been fully addressed and resolved in the design of the new components.

In view of the above, ALSTOM considers that major inspection intervals can be safely extended to 10 years.

8. Reference

ALSTOM Energy Limited report "San Onofre Retrofit Missile Analysis Report", Revision 2 dated 22 June 1998.

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APPENDIX A

FIGURES

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APPENDIX B

TABLES

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ALSTOM LARGE STEAM TURBINES FOR NUCLEAR APPLICATIONS EMPLOYING WELDED ROTOR TECHNOLOGY

Plant	Output MW	Order Date	LP Rotors Per Unit	Operating Hours	Service Data Up To
CHINON B1, FRANCE	969	1977	2	100146	9/97
CHINON B2, FRANCE	969	1977	2	94028	9/97
CHINON B3, FRANCE	969	1980	2	73056	9/97
CHINON B4, FRANCE	969	1981	2	70180	9/97
CRUAS 1, FRANCE	969	1977	2	95923	9/97
CRUAS 2, FRANCE	969	1978	2	87807	9/97
CRUAS 3, FRANCE	969	1979	2	92532	9/97
CRUAS 4, FRANCE	969	1979	2	86618	9/97
SAINT LAURENT B1, FRANCE	969	1974	2	96263	9/97
SAINT LAURENT B2, FRANCE	949	1974	2	102648	9/97
ULCHIN 9, S. KOREA	987	1982	2	58881	4/97
ULCHIN 10, S. KOREA	987	1982	2	60116	2/97
DOEL 4, BELGIUM	1125	1974	2	81219	3/97
TIHANGE 3, BELGIUM	1125	1974	2	93976	6/97
PALUEL 1, FRANCE	1347	1977	3	81821	9/97
PALUEL 2, FRANCE	1347	1978	3	80619	9/97
PALUEL 3, FRANCE	1347	1979	3	77072	9/97
PALUEL 4, FRANCE	1347	1981	3	73760	9/97
FLAMANVILLE 1, FRANCE	1347	1980	3	75009	9/97
FLAMANVILLE 2, FRANCE	1347	1981	3	70656	9/97
SAINT ALBAN 1, FRANCE	1347	1979	3	70455	9/97
SAINT ALBAN 2, FRANCE	1147	1980	3	65014	9/97
CATTENOM 1, FRANCE	1325	1980	3	63835	9/97
CATTENOM 2, FRANCE	1325	1981	3	64669	9/97
CATTENOM 3, FRANCE	1325	1983	3	50423	9/97
CATTENOM 4, FRANCE	1325	1985	3	44390	9/97
BELLEVILLE 1, FRANCE	1325	1981	3	65347	9/97
BELLEVILLE 2, FRANCE	1325	1982	3	62528	9/97
NOGENT 1, FRANCE	1325	1982	3	62010	9/97
NOGENT 2, FRANCE	1325	1983	3	60118	9/97
GOLFECH 1, FRANCE	1325	1984	3	51271	9/97
GOLFECH 2, FRANCE	1325	1987	3	28246	9/97
PENLY 1, FRANCE	1325	1984	3	50811	9/97
PENLY 2, FRANCE	1325	1986	3	38318	9/97
CHOOZ B1, FRANCE	1532	1985	3	4726	9/97
CHOOZ B2, FRANCE	1532	1988	3	1965	9/97
CIVAUX 1, FRANCE	1517	1992	3		
CIVAUX 2, FRANCE	1517	1993	3		
TIHANGE 1-1, BELGIUM (REPLANT)	504	1993	2		
TIHANGE 1-2, BELGIUM (REPLANT)	504	1993	2		
TIHANGE 2 BELGIUM (REPLANT)	955	1994	3		
DOEL 3, BELGIUM (REPLANT)	955	1994	3		
SAN ONOFRE 2, USA (REPLANT)	1170	1996	3		
SAN ONOFRE 3, USA (REPLANT)	1170	1996	3		
CP 1, FRANCE (REPLANT)	1000	1996	3		
Total = 119 Rotors					

Table 1

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Table 2:
Reference List for ALSTOM Large Steam Turbines Employing "Optiflow" LP Turbines

Plant, Unit	**Customer**	**Location**	**Output (MW)**	**Speed (RPM)**	**Order date**	**First Operation**	**Service Hours**	**Service Data up to**
Chinon A3-1	Electricité de France (EDF)	France	250	3000	1961	1966	98060	Jun-90
Chinon A3-2	Electricité de France (EDF)	France	250	3000	1961	1966	92425	Jun-90
Merwedehaven 3	Gemeentelijk Energiebedrijf (GEB)	Netherlands	150	3000	1962	1965	122991	Dec-93
Pont du Sambre 3	Electricité de France (EDF)	France	250	3000	1963	1967	138738	Sep-95
Saint Laurent A1-1	Electricité de France (EDF)	France	250	3000	1963	1969	128123	Jul-92
Saint Laurent A1-2	Electricité de France (EDF)	France	250	3000	1963	1969	119594	Jul-92
Fievo 1	Provinciaal Geldersche Electriciteits Maatschappij	Netherlands	180	3000	1964	1968	119347	Mar-95
Fievo 2	Provinciaal Geldersche Electriciteits Maatschappij	Netherlands	180	3000	1964	1969	105340	Mar-95
Le Havre 2	Electricité de France (EDF)	France	600	3000	1964	1969	173044	Sep-95
Aliveri 3	Public Power Corporation (PPC)	Greece	150	3000	1965	1968	175711	Apr-93
Merwedehaven 4	Gemeentelijk Energiebedrijf (GEB)	Netherlands	150	3000	1965	1968	134054	Sep-95
Bouchain 1	Electricité de France (EDF)	France	250	3000	1965	1970	114201	Sep-95
Diemen 1	Provinciaal Electriciteitsbedrijf van	Netherlands	180	3000	1966	1970	108188	Dec-93
Diemen 2	Provinciaal Electriciteitsbedrijf van	Netherlands	180	3000	1966	1970	103028	Dec-93
Vandellos 1-1	Hispano-Grancesa de Energia SA	Spain	250	3000	1966	1972	135322	Oct-89
Vandellos 1-2	Hispano-Grancesa de Energia SA	Spain	250	3000	1966	1972	134919	Oct-89
Saint Laurent A2-1	Electricité de France (EDF)	France	250	3000	1966	1971	114483	May-92
Saint Laurent A2-2	Electricité de France (EDF)	France	250	3000	1966	1971	110068	May-92
Bouchain 2	Electricité de France (EDF)	France	250	3000	1966	1970	105555	Sep-95
Algeciras	Compania Sevillana de Electricidad SA	Spain	250	3000	1967	1970	94500	Apr-93
Le Maxe 1	Electricité de France (EDF)	France	250	3000	1967	1971	119745	Dec-95
Le Maxe 2	Electricité de France (EDF)	France	250	3000	1967	1971	125950	Dec-95
Aliveri 4	Public Power Corporation (PPC)	Greece	150	3000	1968	1969	167851	Apr-93
Puertollano	Compania Sevillana de Electricidad SA	Spain	220	3000	1968	1972	141107	Apr-95
Emile Huchet 5	Houilléres du Bassin de Lorraine (HBL)	France	294	3000	1969	1973	137809	Sep-95
Tihange 1-1	Société Belgo-Française d'Energie Nucléaire	Belguim	504	1500	1969	1975	137013	Apr-94
Tihange 1-2	Société Belgo-Française d'Energie Nucléaire	Belguim	504	1500	1969	1975	137560	Apr-94

Table 2:
Reference List for ALSTOM Large Steam Turbines Employing "Optiflow" LP Turbines

Plant, Unit	Customer	Location	Output (MW)	Speed (RPM)	Order date	First Operation	Service Hours	Service Data up to
Le Havre 3	Electricité de France (EDF)	France	600	3000	1969	1973	56461	Sep-95
Ptolemais 4	Public Power Corporation (PPC)	Greece	300	3000	1970	1973	150375	Mar-95
Lavrion 2	Public Power Corporation (PPC)	Greece	300	3000	1970	1973	147048	Apr-95
Flevo 3	Provinciaal Geldersche Electriciteits Maatschappij	Netherlands	460	3000	1970	1973	111242	Mar-95
Tarbert 3	Electricity Supply Board (ESB)	Ireland	256	3000	1971	1976	77197	Sep-93
Tarbert 4	Electricity Supply Board (ESB)	Ireland	256	3000	1971	1977	63102	Oct-92
Kardia 1	Public Power Corporation (PPC)	Greece	300	3000	1971	1974	124027	Feb-92
Kardia 2	Public Power Corporation (PPC)	Greece	300	3000	1971	1976	130000	Dec-93
Lage Weide	PGUS	Netherlands	260	3000	1972	1976	116161	Feb-95
Poolbeg	Electricity Supply Board (ESB)	Ireland	270	3000	1972	1978	90393	Jun-95
Aghada	Electricity Supply Board (ESB)	Ireland	270	3000	1975	1980	92613	May-94
Gelderland 13	Provinciaal Geldersche Electriciteits Maatschappij	Netherlands	618	3000	1976	1981	100303	Sep-95
Emile Huchet 6	Houillères du Bassin de Lorraine (HBL)	France	600	3000	1978	1981	75997	Sep-95
Aghios Dimitrios 1	Public Power Corporation (PPC)	Greece	320	3000	1980	1984	79645	May-95
Aghios Dimitrios 2	Public Power Corporation (PPC)	Greece	320	3000	1980	1984	94696	Jul-93
Gardanne 5	Houillères du Bassin du Centre et du Midi	France	600	3000	1980	1984	50884	Sep-85
Jorf Lasfar 1	Office National de l'Energie (O.N.E.)	Morocco	330	3000	1990	1994	18500	Jun-96
Jorf Lasfar 2	Office National de l'Energie (O.N.E.)	Morocco	330	3000	1990	1995	13500	Jun-96
Chambers Works	Bechtel Power Corporation	USA	285	3600	1991	1993	13000	Feb-96
Sual 1	CEPA	Philippines	660	3600	1995			
Sual 2	CEPA	Philippines	660	3600	1995			
San Onofre 2 (Replant)	Southern California Edison	USA	1170	1800	1996			
San Onofre 3 (Replant)	Southern California Edison	USA	1170	1800	1996			

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TABLE 3

Forgings for SONGS welded rotors

Chemical composition	ALSTOM Specification	ASTM A471 Class 2 (near equivalent)
C		0.25 max
Si		0.15 - 0.35 (0.10 max if VCD steelmaking is specified)
Mn		0.70 max
S		-
P		-
Ni		2.00 - 4.00
Cr		0.75 - 2.00
Mo		0.20 - 0.70
V		0.05 min
P+Sn		
Al		-
Cu		-
As		-
Sb		For information
Melting Route	Electric furnace process and vacuum treated	Electric furnace process and vacuum treated
Mechanical Properties at periphery of forging		
Tensile strength, N/mm²(ksi)		725 min (105 min)
0.2% yield strength, N/mm²(ksi)		585 - 725 (85 - 105)
Elongation, minimum(%)		
Longitudinal(L_0=5d)	15	
Longitudinal(L_0=50mm)		19
Transverse(L_0=5d)	14	
Reduction in area, minimum (%)	for information	50
Charpy V-notch impact energy, minimum, (J)		
Longitudinal		
Transverse		65 at +20°C
FATT, maximum		-18°C
NDE		
Visual examination	All surfaces	Optional
Magnetic particle examination	All locally ground surfaces	Optional
Ultrasonic examination	Entire volume using compression wave probes and/or angle compression wave probes	Examination from all surfaces to demonstrate freedom from detrimental internal indications, as practice A 388

Table 4 - Actual Mechanical Properties of Forgings for SONGS Rotors.

PROPRIETARY INFORMATION

ENCLOSURE 3

ALSTOM LOW PRESSURE TURBINE ROTOR REPLACEMENT REPORT
PROPRIETARY VERSION

San Onofre Nuclear Generating Station
Units 2 and 3