BJRS

BRAZILIAN JOURNAL
OF
RADIATION SCIENCES
10-03A (2022) 01-14

SBPR
Sociedade Brasileira de Proteção Radiológica

IEA-R1 Renewed Primary System Pump B1-B Nozzles Stress Analysis

Faloppa[a], A. A.; Fainer[a], G.; Figueiredo[a], C. D. R.; Carvalho[a], D. S. M.; Mattar Neto[a], M.

[a] *Instituto de Pesquisas Energéticas e Nucleares (IPEN/CNEN- SP) São Paulo – SP – Brasil*
afaloppa@ipen.br

ABSTRACT

The present report is a summary of the structural analysis of the pump nozzles applying the finite element method by using the Ansys computer program. The IEA-R1 RR is an open pool-type moderated and cooled by light water using beryllium/graphite as a reflector. The reactor can reach up to 5MW of thermal power cooled by the primary and secondary systems. The primary coolant system consists of a piping arrangement, a decay tank, two pumps, and two heat exchangers. The primary pump B1-B presented some failures requiring refurbishment by a new one. The pump used in the IEA-R1 must meet the requirements inherent to the nuclear installation, in addition to the operational requirements for rotating equipment, such as flow and pressure, and structural integrity of the body and nozzles. The supplier specified the type of pump suitable for the System. The pump furnished granted mechanical allowable loads for the nozzles that were lower than the loads imposed by the piping on the nozzles. To enable the installation of the pump in the primary circuit, new support was inserted in the piping system next to the pump minimizing efforts and deformations. A piping stress analysis was carried out to obtain the new efforts imposed on the nozzles. For validation of the motor pump set, a verification of the nozzles was done compared with API 610 standard loads, and the allowable loads of the provider. Finally, a structural analysis of the pump nozzles with the new loads was developed using the finite element method. The calculated stresses meet the limits prescribed by the ASME code; therefore, the new B1-B Pump is approved for operation at the IEA-R1 Nuclear Research Reactor primary circuit.

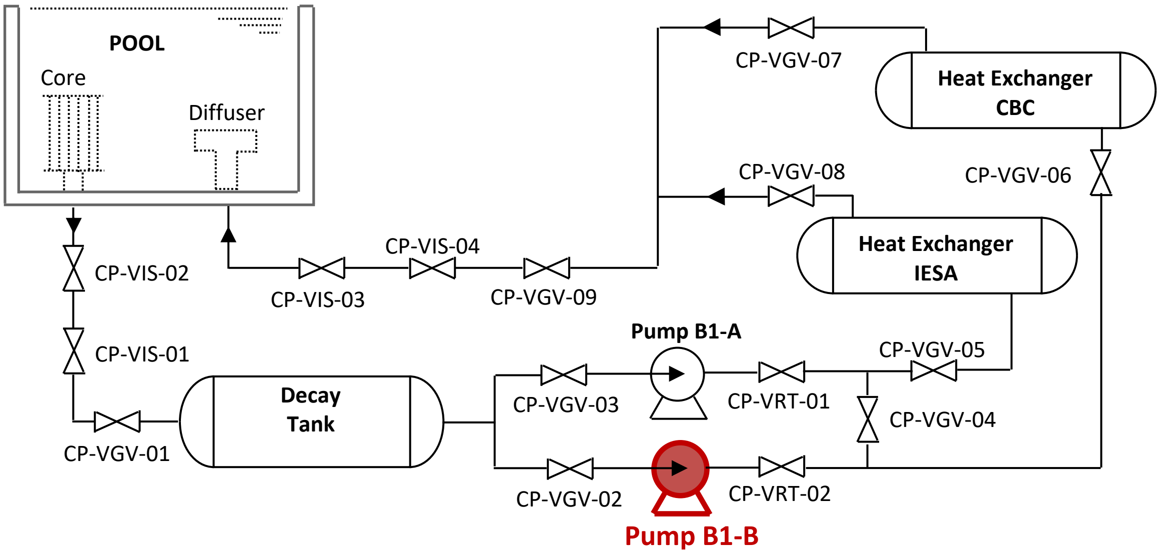
Keywords: **Research Reactor, IEA-R1, Pump nozzles, Finite element, Ansys.**

ISSN: 2319-0612
DOI: https://doi.org/10.15392/2319-0612.2022.1892
Submitted: 2022-01-28
Accepted: 2023-01-25

1. INTRODUCTION

The IEA-R1 is an open pool-type research reactor moderated and cooled by light water using beryllium/graphite as a reflector. The reactor can reach up to 5MW thermal power cooled by primary and secondary systems. The primary coolant system consists of a piping system, a decay tank, two pumps, and two heat exchangers [1, 2]. All parts of the primary system are monitored by the Data Acquisition system (DAS), which provides information for the Maintenance Management Program.

Figure 1: *Simplified flowchart of the Primary Circuit of the IEA-R1 Reactor*



Source: Faloppa *et al*. (2020) [3]

This way the pump B1-B presented some failure requiring refurbishment by a new one. Every pump equipment manufacturer has its requirements for its specific pump models. The new pump must follow some requirements and specific codes, design, and operational requirements of the IEA-R1 Reactor [4].

Aiming for the best equipment purchase a detailed specification was prepared to acquire the new pump, in the same way, the pump must meet the operational requirements for rotating equipment, such as flow and pressure, the structural integrity of the body, and nozzles. The supplier specified the type of centrifugal pump suitable for the System. The supplied pump presented mechanical allowable loads for the nozzles that were lower than the loads imposed by the piping on the nozzles. To enable the installation of the pump in the primary circuit, new support was inserted in the piping system next to the pump minimizing efforts and deformations. In this way, a piping stress analysis was carried out to obtain the new efforts applied to the nozzles and used for validation of the motor pump set. In addition, to approve the set verification of the nozzles was done comparing with API 610 standard loads [5], and the allowable loads of the supplier.

Finally, a structural analysis of the pump nozzles with the new loads was developed. This report presents a summary of the structural evaluation of the pumping nozzles by applying the elastic stress analysis method by the Finite Element Model (FEM) [4]. The pump and material specifications are based on the data book of supply company "*AcquaVitae*" for the pump model EQHE-250-29 [6, 7].

2. METHODOLOGY

The stress analysis of the new B1-B pump nozzles was performed according to the methodology presented below. First, all properties of the primary system and the new pump were collected. Tables 1 and Table 2 summarizes the properties used to analyze the pump.

Table 1: Design and Operational Process Data of the Reactor

	Pressure (MPa)	Temperature (ºC)
Design	0.69	65.6
Service	0.27	43.9

Source: BABCOCK & WILCOX Co [1]

Table 2: Pump Material Specification.

	Material	E (MPa) (Modulus of Elasticity)	S_U (MPa) (Ultimate Stress)	S_Y (MPa) (Yield Stress)	S_H (MPa) (Hot Stress)
Nozzles	A351 CF8	195000	485	205	136
Body	A743 CF8M	195000	485	205	136

Source: ASME [7]

The allowable loads (S_H) were obtained by the following correlation (minor value):

$$S_H = mínimo\left[\frac{S_U}{3.5} : \frac{S_Y}{1.5}\right] \quad (1)$$

The new pump body demands small modifications in the piping trace. Therefore, the review of the piping stress analysis [3] was done and demanded the addition of new piping support consequently redistributing the values of the forces and moments in the piping system. The calculation model was done following the new routing of the lines and it was simulated with the computer program Caesar II [8].

The applied loads used in this analysis come from the new piping condition. A 3D model of the new pump was developed based on a preliminary model provided by the supplier, and it is used in the FEM analysis model processing in the Ansys program [9].

Figure 2 shows the pump motor set and Figure 3 shows the 3D model used by the Ansys program to perform the stress analysis of the pump nozzles. The body pump was decoupled from the skid set to better analyze the nozzles and the 3D model developed was simplified.

Figure 2: *IEA-R1 New Pump motor set B1-B*

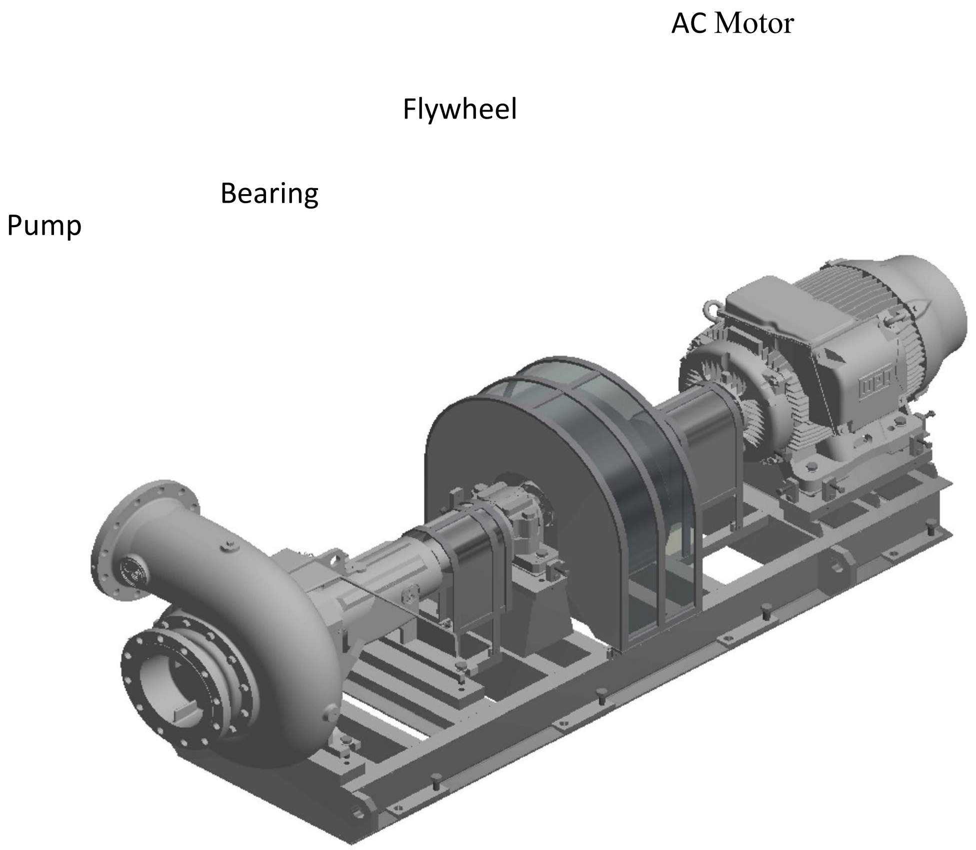
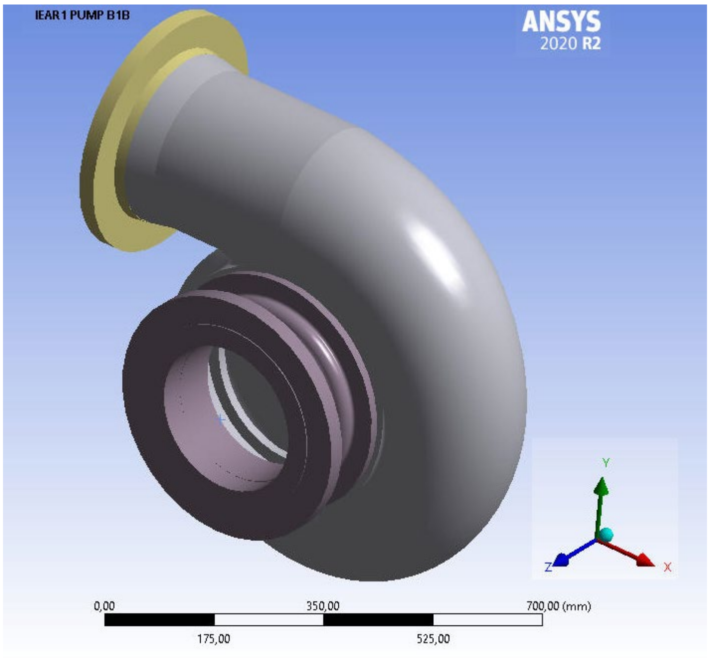


Figure 3: *Ansys 3D Model*



Source: Author

Table 3 shows the applied loads considering design and service/operational conditions adding mechanical loads and mechanical decoupling loads.

Table 3: Loads Considered in the Analysis.

Design Condition	Operational Condition
Design Pressure	Service Pressure
Dead Weight	Dead Weight
Mechanical Loads	Operating Temperature
Mechanical Decoupling Loads	Mechanical Loads
	Mechanical Decoupling Loads

Table 4 shows the load cases and specific loads considering design and service conditions. Case **1 (OPE)** means Pump B1-B in line with Heat Exchanger 1 (IESA), Case **2 (OPE)** means Pump B1-B in line with Heat Exchanger 2 (CBC) and the load Case **3 (SUS)** means Sustained (deadweight) as described in the following.

Table 4 Load Cases Considered in the Stress Analysis

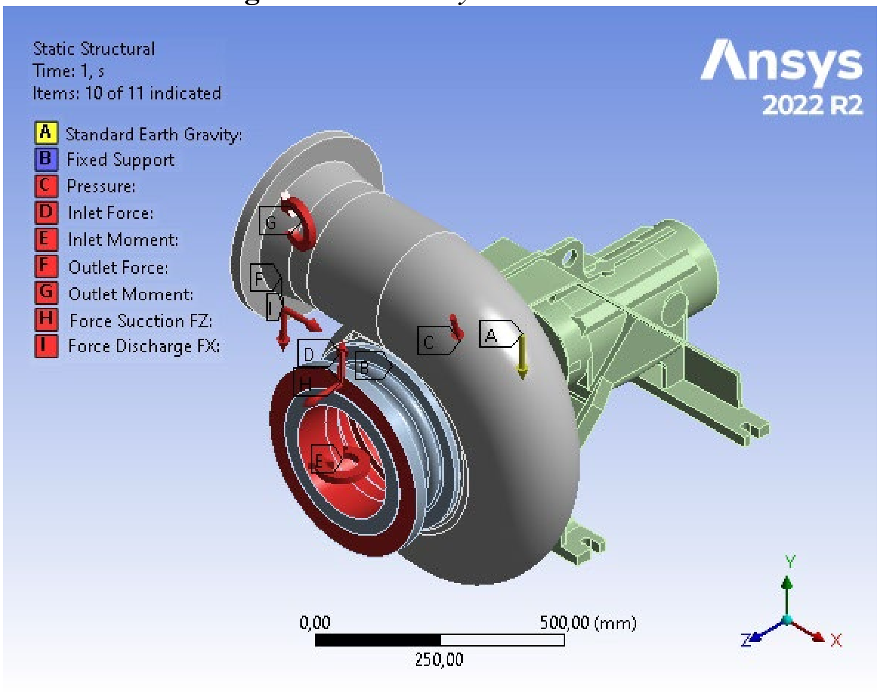
1 (OPE) weight (pipe+water+valve+nozzle) + thermal (pump B1-B + HE-1 – "on")
2 (OPE) weight (pipe+water+valve+nozzle) + thermal (pump B1-B + HE-2 – "on")
3 (SUS) weight (pipe+water+valve+nozzle)

Table 5 shows the applied forces (N) and Moments considering design and service conditions.

Table 5: Forces and Moments

Nozzles	Load Case	Force (N)			Moment (Nm)		
		X	Y	Z	X	Y	Z
Suction	1 (OPE)	-5728	6183	-2536	-8231	-5310	-
	2 (OPE)	-5831	6685	-2824	-8646	-5405	-
	3 (SUS)	-104	52	-114	4	-118	-5
Discharge	1 (OPE)	1814	-2763	12443	-609	9744	1803
	2 (OPE)	192	-2831	2028	-429	1599	1891
	3 (SUS)	-140	-2845	-98	-393	-64	1909

Figure 4: *Boundary conditions*



Source: Author

Figure 4 presents the boundary condition set on the Pump. The fixed support was imposed in the pump body opposite of inlet nozzle.

The stress analysis was developed according to the ASME code VIII, Division 1 [10]. The code does not contemplate the requirements of design by analysis of ASME VIII, Division 2, [11], which is usually employed in the stress analysis of equipment nozzles. Nevertheless, the paragraph "U-2(g)" of ASME VIII, Division 1, allows the designer develops procedures for equipment design, where the code does not have specific rules, setting the design criteria of ASME VIII, Division 1.

These design criteria are satisfied by applying Part 4 or Part 5 of ASME VIII, Division 2, with the allowable stress from ASME VIII, Division 1 [10]. Therefore, to evaluate the protection against plastic collapse, the results of linear elastic stress analysis of a component, subject to loads due to design pressure and mechanical loads, may be classified and compared to associated limits, with the allowable stress S_H= 136 MPa (1) from ASME VIII, Division 1. The equivalent stresses were calculated using the Von Mises criterion. Table 6 shows categories of equivalent stresses and limits defined according to ASME VIII, Division 2, [11].

Table 6: Stress Categories and Limits

$\mathbf{P_m}$	General Primary Membrane Stress		
$\mathbf{P_L}$	Local Primary Membrane Stress		
$\mathbf{P_B}$	Primary Bending Stress		
Q	Secondary Stress		
Limits	$P_m \leq SH$	$P_L \leq 1.5xSH$	$P_L + Q \leq 3.0xS_H$

Source: ASME [11]

The categorization of the linearized equivalent stress was done based on the recommendations given by researchers, mainly Hollinger & Hechmer (H&H) [12], which occurs in the maximum stress region.

The evaluation of stress linearization in the nozzles was analyzed by ANSYS. The high-stress intensity area is spotted on the stress intensity maximum contours, and then the two nodes in this area are selected which can run through the thickness of the nozzle in the chosen area. Values data can be found in the path done by linking the two nodes, and then the results can be calculated and analyzed by the selected path.

3. RESULTS AND DISCUSSION

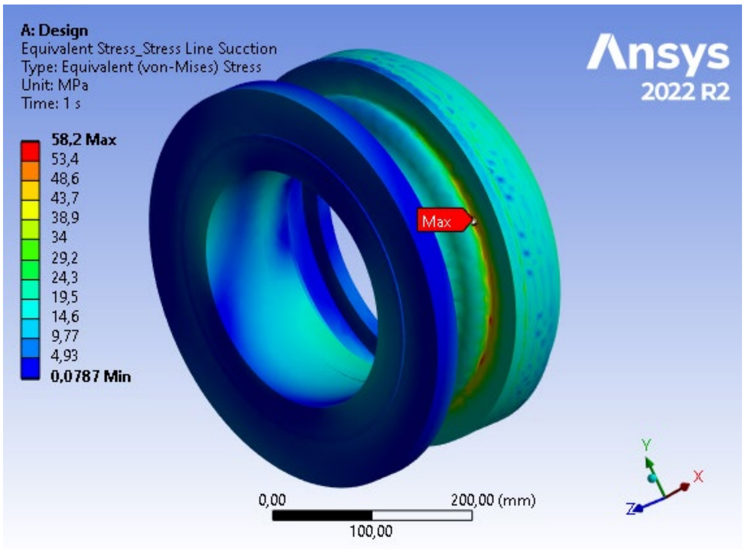
The evaluation of the pump nozzle was conducted following the criteria of API 610 code as described in table 4 and annex F of the code [5] compared with the loads prescribed by the supplier. As stated, this report presents the additional verification to guarantee the safe operation of the reactor. This way a stress analysis of the nozzles was done, and the results were satisfactory as shown below.

The obtained results for the maximum calculated stress and linearized equivalent stress are shown in Tables 7 and 8. Table 7 presents the results of the suction nozzles Stress obtained from Design and Service Loads, and table 8 presents discharge nozzles stress obtained from design and service loads.

Table 7: Suction - Stress Obtained from Design and Service Loads

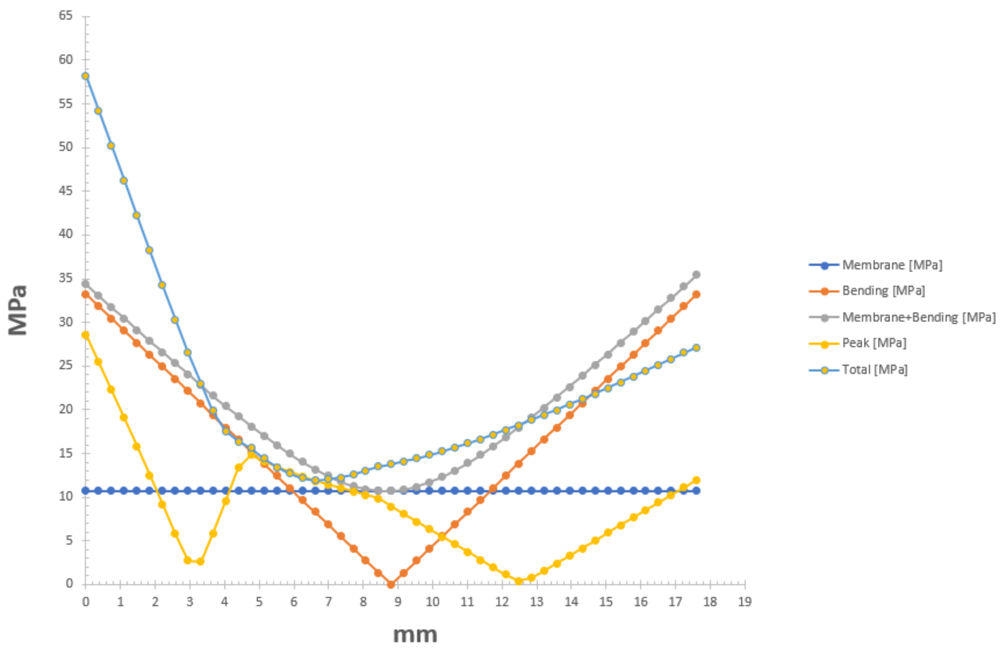
Nozzle	Design				Service			
	Category	**Limit (MPa)**	**Figure**	**Calculated (MPa)**	**Category**	**Limit (MPa)**	**Figure**	**Calculated (MPa)**
	Max. Stress		5	58.2	Max. Stress		7	53.6
Suction	P_M	136.0	6	10.7	P_M	136.0	8	9.7
	P_M+P_B	136.0	6	43.9	P_M+P_B+Q	136.0	8	47.0

Figure 5: *Stress plot for Design loads: Suction*



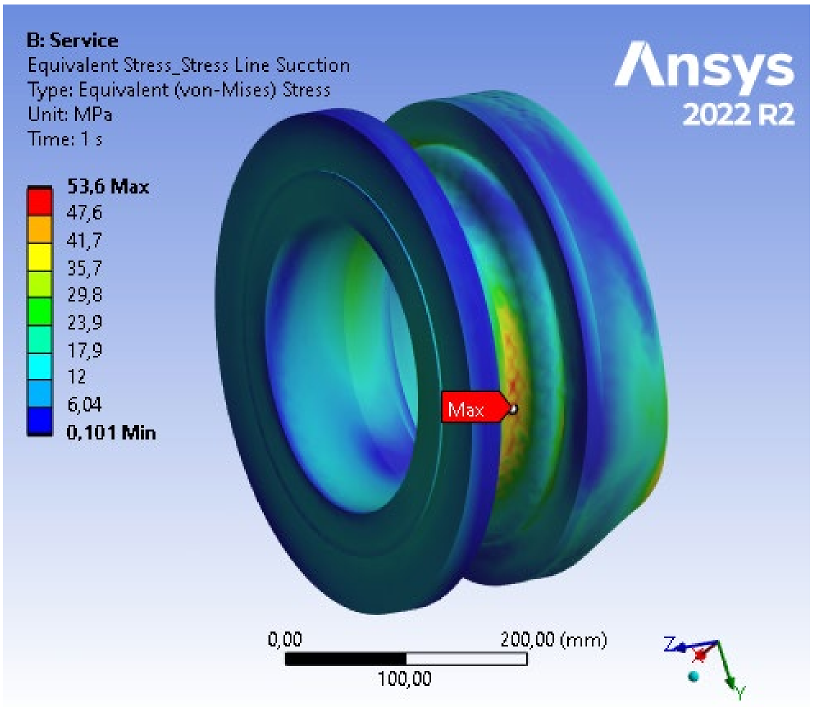
Source: Author

Figure 6: *Linearized Stress plot for Design loads: Suction*



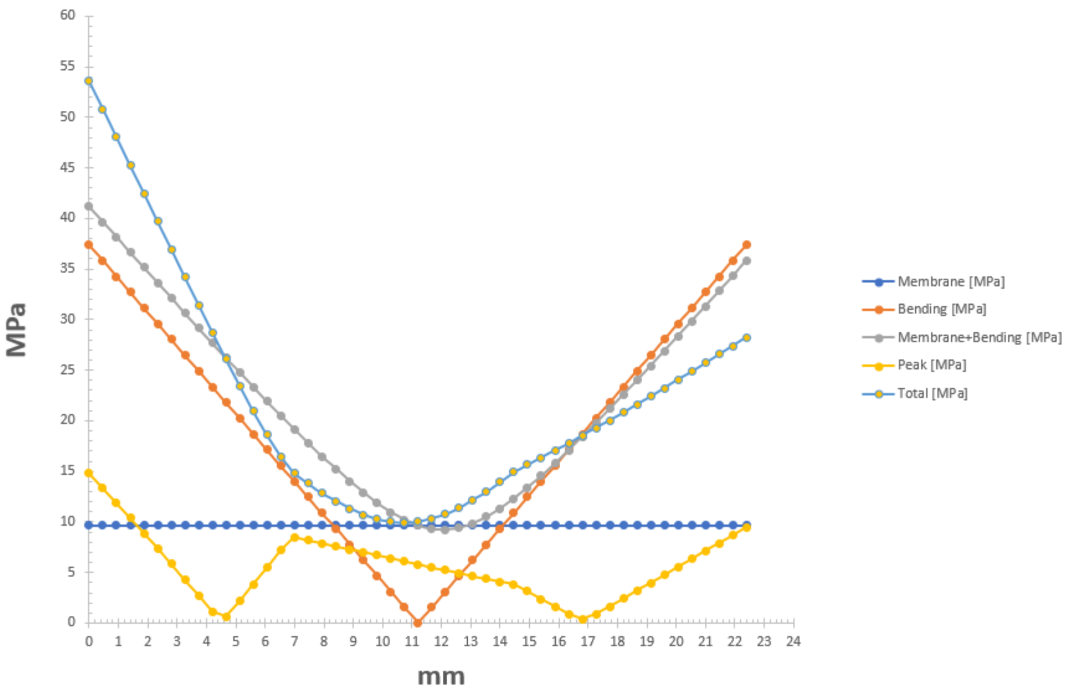
Source: Author

Figure 7: *Stress plot for Service loads: Suction*



Source: Author

Figure 8: *Linearized Stress plot for Service loads: Suction*

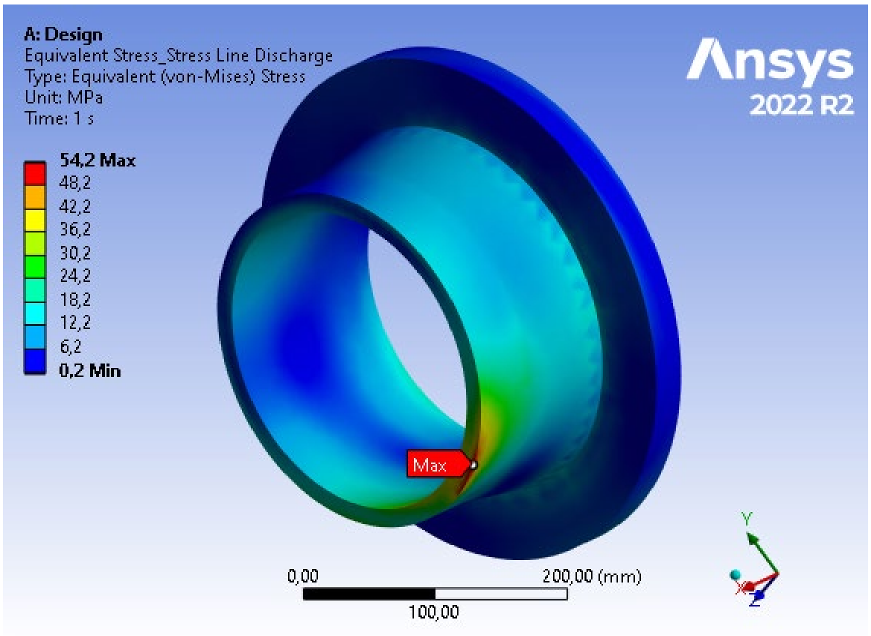


Source: Author

Table 8: Discharge - Stress Obtained from Design and Service Loads

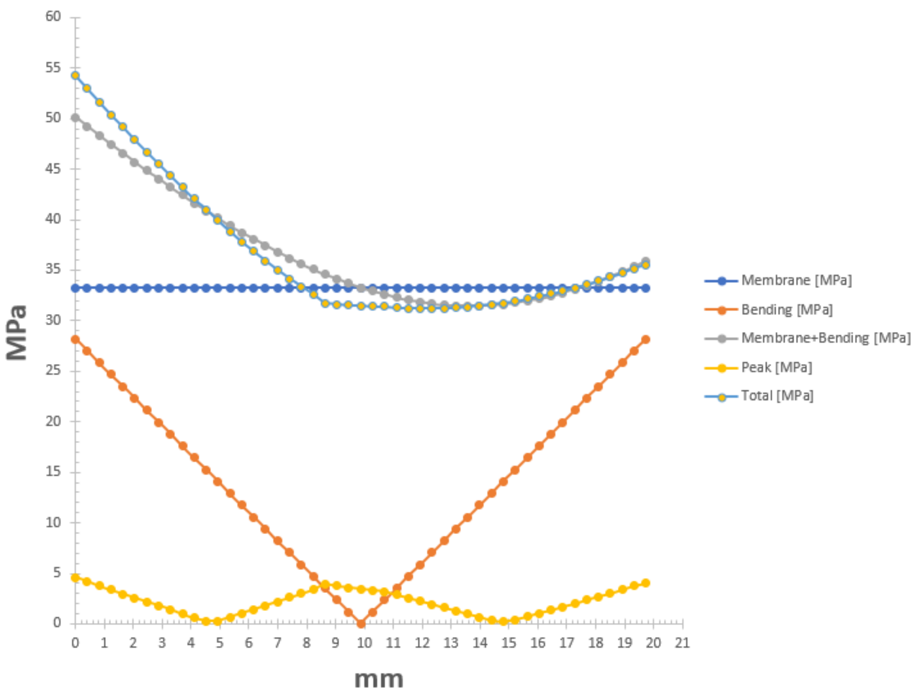
Nozzle	Design				Service			
	Category	Limit (MPa)	Figure	Calculated (MPa)	Category	Limit (MPa)	Figure	Calculated (MPa)
Discharge	Max. Stress		9	54.2	Max. Stress		11	35.4
	P_L	205.0	10	33.3	P_L	205.0	12	27.0
	P_L+P_B	205.0	10	61.4	P_L+P_B+Q	410.0	12	34.0

Figure 9: *Stress plot for Design loads: Discharge*



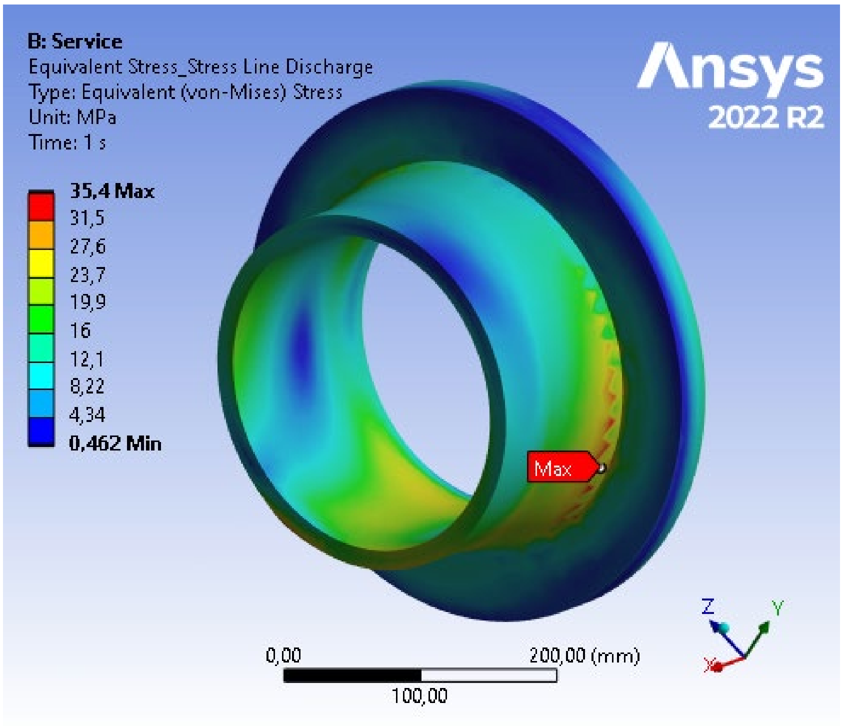
Source: Author

Figure 10: *Linearized Stress plot for Design loads: Discharge*



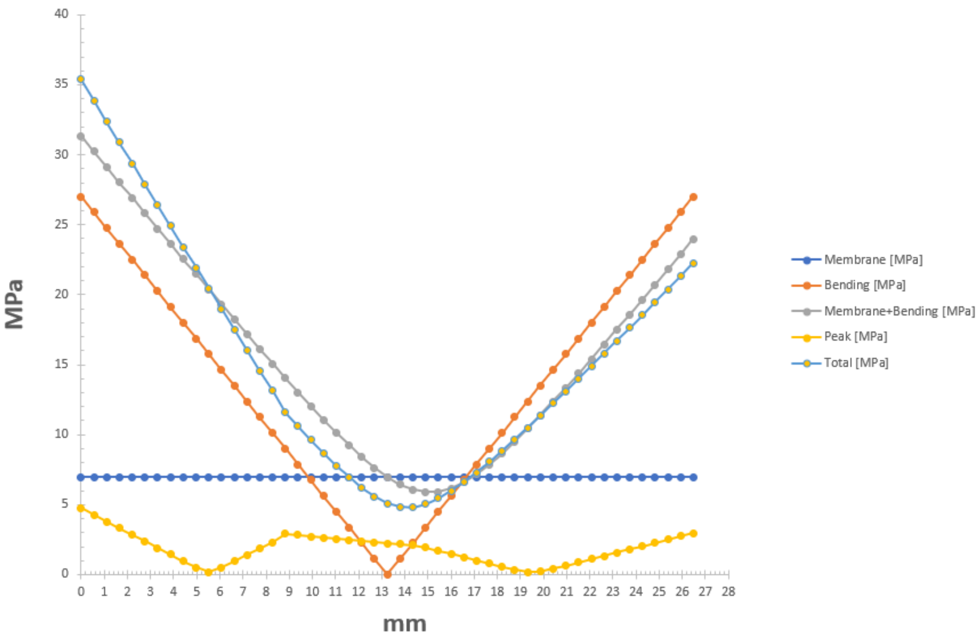
Source: Author

Figure 11: *Stress plot for Service loads: Discharge*



Source: Author

Figure 12: *Linearized Stress plot for Service loads: Discharge*



Source: Author

The mapping of the *Von Misses* equivalent stress results for suction and discharge nozzles in the design and service condition as calculated forms the basis for determining the maximum stress.

The maximum stress is spotted in Figures 5, 7, 9, and 11, while the maximum values and linearized values of stress are presented in figures/graphic 6, 8, 10 and 12. The maximum values are listed in Tables 7 and 8. In Table 7, in the column calculated for suction nozzles considering design and service conditions, are presented the values for Maximum Stress/Von Misses, Membrane and Bending. In the same way, in Table 8 are presented in the column calculated for the same obtained values for discharge considering design and service conditions.

The maximum value calculated in the Suction Nozzle presented in table 7 is 58,2 MPa to Design Maximum Stress, represent 43% of the Limit for Design. Likewise, the value for Service 53,6 MPa represent 25% of the Limit for Service. In the same way the, the values and percentage for the other criteria presents are lesser.

This way, the value calculated in the Discharge Nozzle presented in table 8 is 54,2 MPa to the Design Maximum Stress, represent 40% of the Limit for Design. Similarly, the value for Service represents 18% of the Limit for Service.

As can be seen from the result presented in the above paragraphs and tables, the pump nozzle can satisfy the stress intensity requirement in the ASME code criteria.

4. CONCLUSION

In the present work, the stress analysis of the suction and discharge nozzles of the new B1-B pump was carried out with the development of a numerical calculation model applying the Finite Element Method with the computer program for structural analysis Ansys. The calculated stresses at the suction and discharge nozzles of the new B1-B pump presented in tables 7 and 8, meet the limits, prescribed by the ASME code, Section VIII, Division 1 & 2, for the plant in the design and operating condition. Therefore, the new B1-B Pump is approved for operation at the IEA-R1 Nuclear Research Reactor primary circuit.

ACKNOWLEDGMENT

The authors are grateful to IPEN/CNEN for the support of this work and the help of colleagues in doing this work, particularly the staff from the IEA-R1 Reactor.

REFERENCES

[1] BABCOCK & WILCOX Co, Instruction Book, **The Babcock & Wilcox Co**. – Vol. 1, 1957.

[2] IPEN, CEN, RAS **Relatório de Análise de Segurança do Reator IEA-R1**, cap. 6, 1997.

[3] FALOPPA, A. A. e FAINER, G., Análise de Tensões dos bocais da Nova Bomba B1-B do Circuito Primário do Reator IEA-R1, IPEN, CEN, **IPEN-CEN-PSE-IEAR1-139-00** RELT-001-00, 2020.

[4] FALOPPA, A. A. e FAINER, G., Avaliação Estrutural das Tubulações da Nova Bomba B1-B do Circuito Primário do Reator IEA-R1, IPEN, CEN, **IPEN-CEN-PSE-IEAR1-139-00** RELT-002-00, 2020.

[5] API - American Petroleum Institute, **API Standard 610** - Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries, 2004.

[6] ACQUA VITAE, Data Book – Bomba Centrifuga, **AcquaVitae Tecnologia em Bombeamentos**, 2020.

[7] ASME - American Society of Mechanical Engineers -**ASME Boiler and Pressure Vessel Code**, Section II, Part D, Properties, 2007.

[8] HEXAGON, Caesar II, **Structural Analysis Guide & Theory Reference Manual,** 2008.

[9] ANSYS Inc., Ansys Mechanical R2 2021, ANSYS Inc, 2021

[10] ASME - American Society of Mechanical Engineers - **ASME Boiler and Pressure Vessel Code**, Section VIII, Division 1, Rules for Construction of Pressure Vessels, 2007.

[11] ASME - American Society of Mechanical Engineers - **ASME Boiler and Pressure Vessel Code**, Section VIII, Division 2, Alternative Rules - Rules for Construction of Pressure Vessels, 2007.

[12] HOLLINGER, G. L.; HECHMER, J. L., Phase 1 Report: Three-Dimensional Stress Criteria, **PVRC Grants 89**-16 and 90-13, New York, NY, 1991.