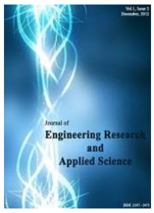
Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 5(2), December 2016, pp 429-441
ISSN 2147-3471 © 2016



The investigation of performance analysis and cavitation in inline type centrifugal pumps

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Accepted 01 October 2016

Abstract
Using energy and cost of this have gradually increased associated with big developments in industry and technology area. For this purpose, there are some any studies which make energy productivity growth in the world. In this study, energy consumption rates of inline type centrifugal pump from centrifugal pumps is searched, energy productivity in centrifugal pumps, the importance of saving and concerns about using energy productively are mentioned. After history, operation principles, basic types and components of centrifugal pumps were mentioned, the concepts and accounts about pumps were explained. The methods which can be used to regulate performance of pumps were discussed, quantitative examples and superiorities of these examples were investigated. Pump system was considered as a whole and the importance, benefits and providing saving of using high efficiency motor were given place in the study. The definition of cavitation was done, and defined the factors which cause cavitation. The prevention methods from cavitation was explained. Performance and cavitation were tested in inline type centrifugal pumps. Results of the tests, reports of pump performance and pump cavitation were obtained. In the pump performance report, the importance of the most ideal point was explained. The nagations were explained in the pump which was exposed to cavitation.

Keywords: Inline, Pump, Energy Efficiency, Cavitation

1. Introduction

Today, pumps have found a wide variety of usage area. People use pumps in providing water, agricultural irrigation, sprinkling, air conditioning plants, cooling and heating plants, industry, especially chemistry industry, food and drink industry, supplying water need of plants and residences and in many more areas.

With the huge development of industry and technology, usage and cost of of energy has increased gradually. For this purpose, studies about increasing the productivity of energy has been more. As well as producing energy, using energy in a productive way is one of the important subjects for countries any more.

Necessity of energy increases day by day in our country in parallel with increase in population and development in industry, and energy sources cannot fulfill this necessity. Our country meets most of its energy demand by import, for this reason using energy productively is very important not to have a problem in development and industrialization. According to the studies, it is expressed that 30 % the annual energy used can be saved by just using the energy productively [1].

It shouldn’t be forgotten that biggest saving can be done in industry. In our fast growing country there are new industrial businesses each passing day. Each new business places a burden to our country’s energy problem. Turkey’s almost 36% total net energy consume of energy is in industry. According to a research of American Hydraulic Institute, 20% of consumed energy is consumed by pumps. With the help of a good system design and appropriate pump choice, it has been clarified that 30% of this energy can be saved [2].

Almost all of the pumps being used in irrigation work on the basis of centrifuge and they are in many different types and sizes. In the plants where pumps are being used planning and organizing vacuum piping line is the biggest cavitation issue being faced.

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Cavitation is one of the issues that is being faced in every pumping plant, being discoursed in recent years and it has to be considered all the time. Especially using high-flowed and high specific speed pumps has made this subject more important. NPSH characteristics have been obtained by making cavitation analysis only for pump impeller [3].

An alternative method has been found to the classic method in which assuming three percent flow decrease is the beginning of cavitation. In this new method, cavitation characteristic has been found by connecting NPSH and the specific level of produced steam volume [4].

When a part of moving fluid is considered, if the local pressure in that area changed in terms of speed of fluid, direction and size because of any causes and if it falls under evaporation pressure which is equal to the temperature of the fluid in that area, a local evaporation occurs in that area. As a result, some blanks is formed in fluid and this blank spots join to general fluid flow, when they reach to the point where fluid is more than steam pressure, they disappear suddenly, the strikes formed as a result of the rush of fluid mass is defined as cavitation. [5].
Pump cavitation is the formation and subsequent collapse or implosion of vapor bubbles in a pump. It occurs when gas bubbles are formed in the pump due to drop in absolute pressure of the liquid below vapor pressure. These gas bubbles occupy space inside the pump and affect the pump's operating pressure and flow. With vapor bubbles in the low-pressure zones of the pump, the motor's energy is wasted expanding the bubbles instead of bringing more liquid into the pump. As the bubbles pass into the pump's high-pressure zones, the motor's energy is wasted compressing the bubbles instead of expelling the liquid from the pump. The bubbles can collapse as they pass from low- to high-pressure zones in the pump. When vapor bubbles collapse inside the pump the liquid strikes the metal parts at the speed of sound. The noise generated from these collisions of gas bubbles into the metal parts of pump sounds like pumping marbles and stones [6,7].

2. Inline Centrifugal Pumps

Inline centrifugal pumps are designed specifically for heating, air conditioning, commercial building and municipal applications. Suction and discharge nozzles are located 180° apart on the same centerline for mounting directly in a pipe line. This eliminates critical pipe alignment for ease of assembly and minimum pipe strain. The inline design eliminates the need for costly foundations and guarantees minimum space requirements. The motor and bracket assembly can be removed from the casing without disturbing the piping. The impeller, mechanical seal, shaft sleeve, and wear rings are therefore accessible for easy maintenance. Mechanical seals and bronze wear ring(s) are supplied as standard on certain pumps. A built in purge system assures proper flushing and venting of seals. The motors are specifically designed for mechanical seal applications. Controlled tolerances and adequate bearings assure long life. Inlıne type centrifugal pump is in figure 1. [8]

Figure 1. Inline type INM 125-315 30 kW 1450 d/d centrifugal pump with engine.

These are some of its usage areas; water supply networks, pressurization plants, irrigation, sprinkling, water drain, filling or draining tanks, cooling and heating systems, hot or cold water systems, hot or cold water circulation, swimming pool water circulation, industrial and recreational facilities, pumping fresh and sea water in ships. When its technical features are analyzed, its flow is between2-500 m^3/h, manometric head and 2-100 m. Inline type INM 125-315 30 kW 1450 d/d centrifugal pump working ranges have been shown in figure 2 [9, 10].

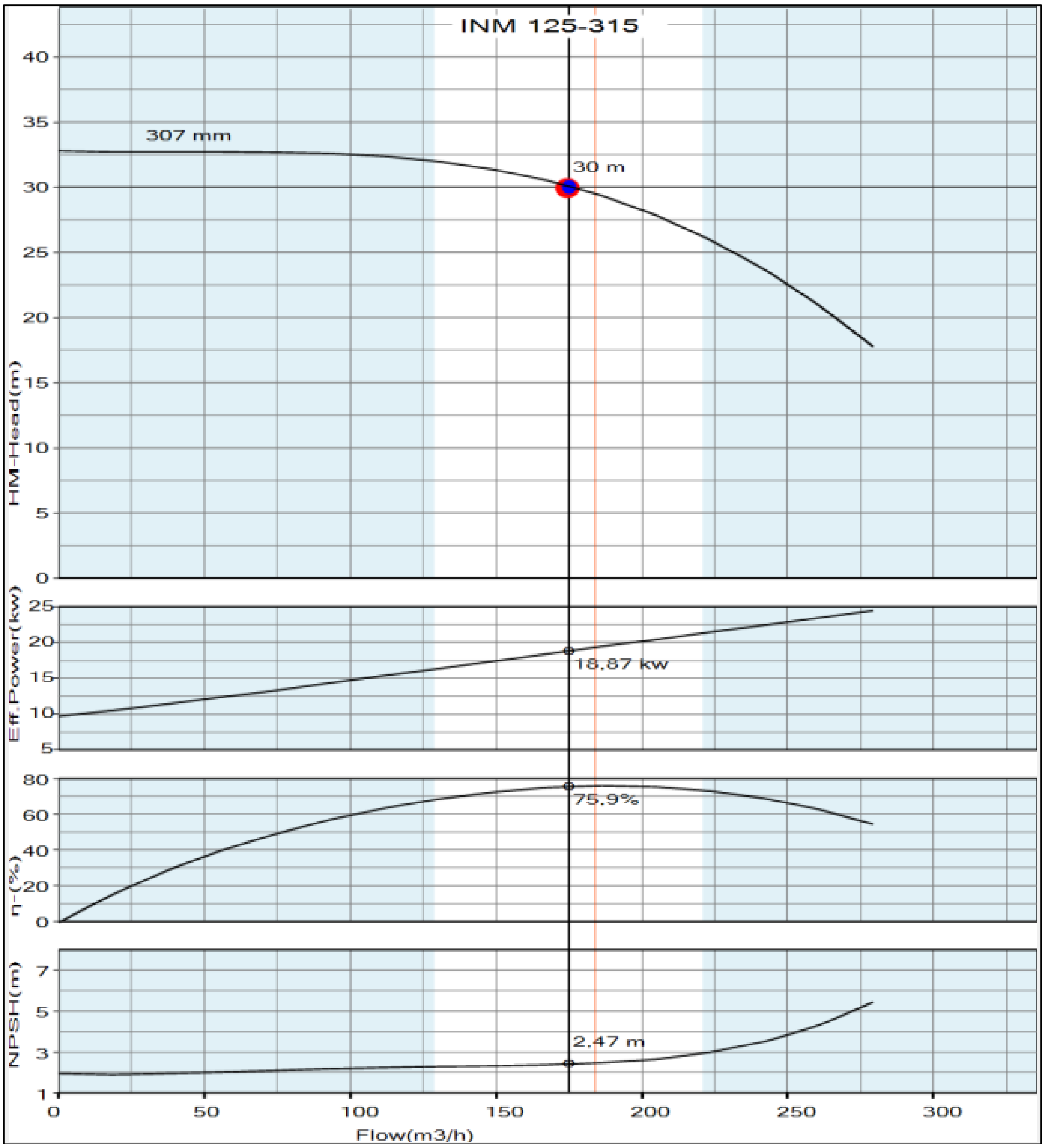

Figure 2. Performance curve of INM 125-315 30 kW 1450 d/d centrifugal pump.

3. Concepts Pump And Accounts

3.1. Flow

Volumetric flow rate is the flow rate of the water pumped, it is usually measured by m³/h or m³/s units and it is variable according to the changes during the operation. Flow rate is up to some variables. These are:

- Pump suction-force temperature

- Pressure conditions
- Size of the pump and input-out put section
- Impeller size
- Impeller rotation speed (rpm),
- Characteristics of the pumped fluid; density and viscosity
- Shape and size of the blanks between the wings

Flow rate is calculated as follows because it is the rate of pumped net fluid volume from the pump force flange [11].

$$Q=vA=v\frac{\pi D^2}{4} \tag{3.1}$$

3.2. Manometric Height Of The Pump

Manometric height of a pump is defined as the gained net (productive) energy of the fluid being pumped between input and output (flanges) per unit weight. Its unit is in length format and that is meter [12].

$$H=\frac{\text{Joule}}{\text{Newton}}=\frac{\text{N.m}}{\text{N}}=\text{m} \tag{3.2}$$

Pump manometric height is calculated as the difference of the flow rates in pump input and output sections.

$$H = H_o - H_i \tag{3.3}$$

$$H = (z_o - z_i) + \frac{p_o - p_i}{\rho g} + \frac{v_o^2 - v_i^2}{2g} \tag{3.4}$$

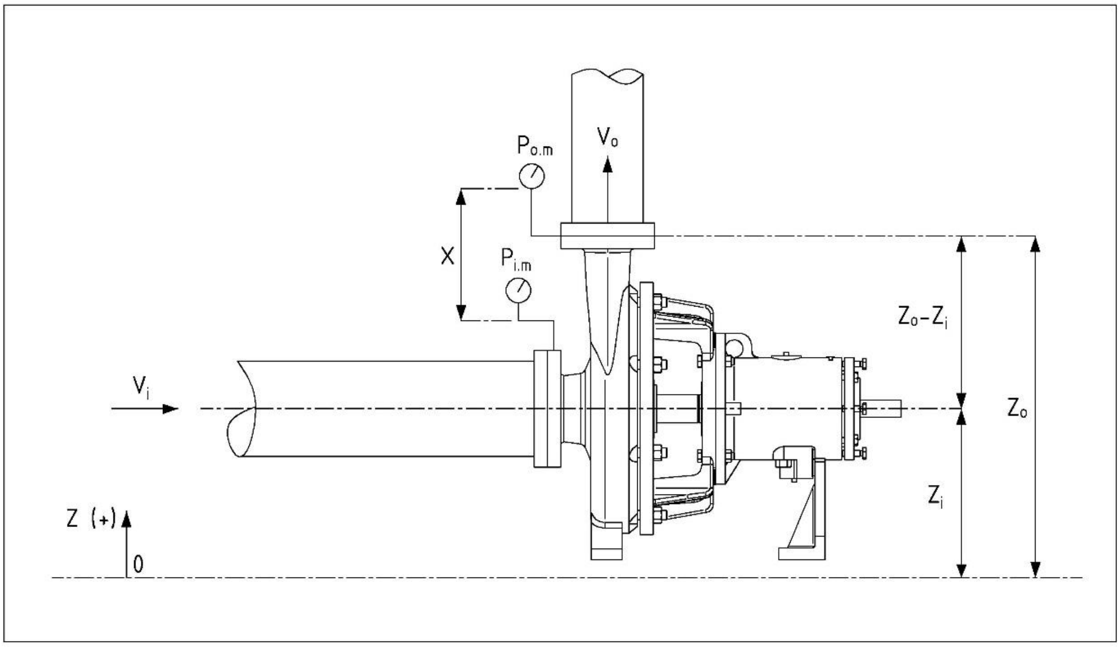

Figure 3. Indices given centrifugal pump.

3.3. Pump Shaft Power

Pump shaft power is the power which is applied to the shaft to drive the pump [13].

$$P=\frac{\rho gQH}{1000\eta} \tag{3.5}$$

3.4. Effective Power

The power which the pump starting engine transmits to pump shaft is called effective power. If the driving system is an electric motor, effective power is the measured power on motor shaft and the losses on motor winding because of heat are out of this power. In other words, obtained power after removing heat resulted winding loss is called pump effective power [12, 13].

3.5. Overall Efficiency Of The Pump

The difference between the mechanical power on pump shaft and hydraulic power gained at the output of the pump is called pump general pump efficiency and it is stated as follows [12, 13].

$$\eta=\frac{\rho gQH}{1000P} \tag{3.6}$$

4. Pump Performance and Cavitation Test

4.1. Performance Test

Determine Inline type centrifuge pump's flow rate to 175 m^3/s, force height to 30 m for its ideal values. INM 125-315 is the pump type that you have to use. Here 125 shows diameters of input and output flanges. 325 shows nominal body size. This is determining process, 262,5 m^3/s which is 1.5 times more than the flow rate value we want and kW motor which has to be one of productivity value was chosen. It has been determined that 30 kW 1500 d/d motor should be used in performance test values. One can see on the pump choice program that the pump's impeller diameter has to be Ø307 mm. The graphic formed after writing pump type and working values to the pump choice is shown in figure 2. The flow rate which has to be reached in any working point, force height, motor productivity, productivity power and NPSH values are available. When a performance test is done for the pump, it has to reach the values in this chart.

The unit in which the pump is tested work in closed loop. This means, the fluid which goes out of the pump from force flange fills the tank again and it is transmitted to vacuum flange. Manometer was connected to the pipe on the force flange and vacuum manometer was connected on the force pipe. Pump type, force flange, impeller diameter, intended flow rate and force height was written to the test report. 30 kW 1450 d/d electric motor values was written to the test report. According to these values motor productivity was calculated as 0.96.
Although the ideal working conditions are obvious, working flow rate will be multiplied 1.5 times and it will be controlled whether the pump will give the required test results or not. Start the motor but the force flange should be barely open. After shaking on the flow in the tank is finished, adjust the pump to the ideal flow rate value. Write the values on the manometer and vacuum manometer, the power, ampere, voltage which motor takes from the network and cosφ values to the test report.

The performance curve should be seen by adjusting the pump in 10 different working conditions. It will be determined whether the pump supplies these 10 different performances. Similarly, force height values and the values on the electric frame was written to the test report. Figure 4 shows the values for different working conditions as a result of our test. The required values has to meet the values in figure 2.

Inline Type Centrifugal Pump		PUMP TEST REPORT			
PUMP	INLINE TİP	ENGINE		MEASUREMENT OF ELECTRONIC FLOW	
Pump Type	INM 125-315	Mark ....:	WAT		
Inlet Flange	125 mm	Power ....:	30,0 KW	Z2-Z1	0 m
Outlet Flanşı	125 mm	Rotatior.............:	1475 d/d		
Impeller Diameter	307 mm	U ....:	380 Volt	DYNAMOMETRY :	KWm.
Flow	175,0 m3/h	I ....:	55,7 Amper	MULTIMETRE	480
Pump Head Hm	30,0 m	Cos F ....:	0,85		4
		h engine ....:	0,96		100

MEASUREMENT OF HYDRAULIC						MEASUREMENT OF POWER					Real Value				
Array No	Speed (d/dak)	Q m3/h	He m	Hb Bar	Hm m	KWm KW	GAUGE KW-m	U Volt	I Amp	Cos F (o)	P1 KW	Q m3/h	Hm m	P2 KW	h p (%)
1	1470	250,0	0,0	2,20	22,4	23,55		382	64,50	0,87	23,55	250,00	22,44	22,67	67,4
2	1478	225,0	0,0	2,55	26,0	22,40		382	63,90	0,87	22,40	225,00	26,01	21,56	73,9
3	1481	200,0	0,2	2,78	28,2	21,00		378	60,80	0,87	21,00	200,00	28,16	20,22	75,9
4	1482	175,0	0,2	2,98	30,2	19,55		382	57,00	0,86	19,55	175,00	30,20	18,82	76,5
5	1484	150,0	0,2	3,07	31,1	18,00		382	54,80	0,86	18,00	150,00	31,11	17,33	73,3
6	1483	125,0	0,4	3,18	32,0	16,50		382	51,80	0,85	16,50	125,00	32,04	15,88	68,7
7	1487	100,0	0,4	3,20	32,2	15,20		383	46,90	0,83	15,20	100,00	32,24	14,63	60,0
8	1487	75,0	0,5	3,23	32,4	14,00		381	42,20	0,81	14,00	75,00	32,45	13,48	49,2
9	1487	50,0	0,6	3,25	32,6	12,80		382	40,00	0,80	12,80	50,00	32,55	12,32	36,0
10	1489	0,0	0,7	3,30	33,0	10,50		382	38,30	0,79	10,50	0,00	32,96	10,11	0,0

Figure 4. INM 125-315 30 kW 1450 d/d pump test report.

When the values tested was controlled in figure 2, it has the same productivity with the tested pump.

With the help of obtained values, a graphic was formed in the test report. The graphic which was formed with obtained values is shown in figure 5.

In figure 5 the pump's ideal working values can be seen. Blue lines show force height, red lines show motor shaft power and green lines show pump productivity. The fall of the force height with the rise of the flow rate can be seen. It has been observed that after a specific flow rate this fall is sharper. Motor shaft power has a straight rise with the rise of the flow rate and it doesn't pass motor's maximum power. In pump productivity graphic, it can be seen that the pump reaches its ideal productivity with ideal working conditions. It has been observed that when the flow rate is zero there is not a productivity, in ideal working conditions the pump is the most productive and when the values are higher than ideal values the productivity falls.

4.2. Cavitation Test

When a pump is under low pressure or high vacuum conditions, suction cavitation occurs. The pump is being "starved" or is not receiving enough flow. When this happens, bubbles or cavities will form at the eye of the impeller. As the bubbles carry over to the discharge side of the pump, the fluid conditions change, compressing the bubble into liquid and causing it to implode against the face of the impeller.

Figure 5. INM 1450 125-315 30 kW / d/d pump graph of the test results.

An impeller that has fallen victim to suction cavitation will have large chunks or very small bits of material missing, causing it to look like a sponge [14]. In figure 6 the difference between cavitation and without cavitation work is shown.

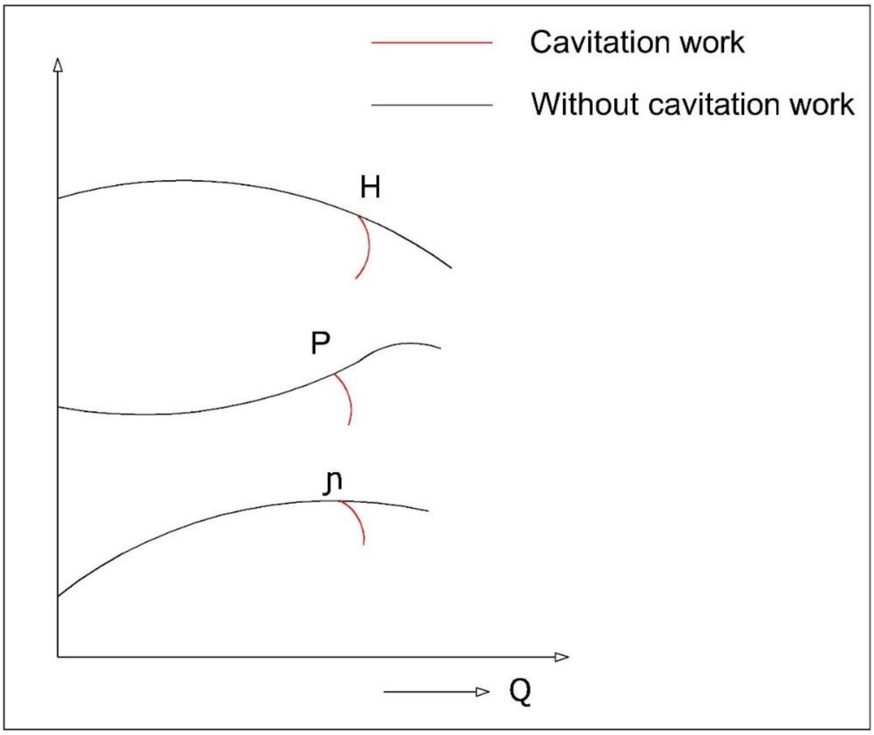

Figure 6. The difference between cavitation and without cavitation work.

In order to prevent cavitation, the pressure in the pump entrance has to be a certain extent higher than the steam pressure constantly.

4.2.1. Net Positive Suction Head (NPSH)

Net positive suction head or NPSH for pumps can be defined as the difference between liquid pressure at pump suction and liquid vapor pressure, expressed in terms of height of liquid column. Suction head is the term used to describe liquid pressure at pump suction in terms of height of liquid column. When vapor pressure is also expressed in terms of equivalent height of liquid column, and subtracted from the suction head, the difference is NPSH available at the pump suction [15].

$$NPSH=\left(\frac{p_s}{\rho g}+\frac{v_s^2}{2g}\right)-\frac{p_v}{\rho g} \qquad (4.1)$$

In here p_s: in the liquid suction port (reference plane) measured absolute static pressure (Pa), v_s: velocity of the liquid at the suction flange section (m/s), p_v: the liquid (the working temperature) the absolute vapor pressure (Pa), : the density of the liquid (kg/m^3), g: gravitational acceleration (m/s^2).

4.2.2. Net Positive Suction Head Required ($NPSH_R$)

Net positive suction head required ($NPSH_R$) is the pressure or energy required for the liquid in a pump to overcome the friction losses from the suction nozzle to the eye of the impeller without causing vaporization.

For normal pump operation the $NPSH_R$ is usually less than the available NPSH in order to avoid cavitation erosion and corrosion [16].

4.2.3. *Net Positive Suction Head Available ($NPSH_A$)*

Net positive suction head available ($NPSH_A$) refers to all the types of energy present in different levels on the suction portion in a pumping system. In short, it is the absolute pressure within the pump's suction port.

This is the overall function of the system that should be calculated in order to prevent the formation of holes or the process of cavitation in pump systems.
Net positive suction head available is especially significant within turbines and centrifugal pumps. These are parts involved in hydraulic systems that are most prone to the formation of holes. If there is cavitation, the pumping power of the impeller vanes drastically elevates, potentially putting a stop to the flow of water [17].

$$NPSH_A=h_{atm}+h_p+h_s-h_{vp}-h_f \qquad (4.2)$$

In here h_{atm}: atmospheric pressure, h_p: surface pressure height, h_s: static height, h_{vp}: evaporation pressure elevation, h_f: friction losses height.

$$\mathrm{NPSH_A} = \frac{p_s}{\rho g} - \frac{p_v}{\rho g} - h_s - h_f \tag{4.3}$$

4.3. Pump Cavitation Test

The manometer was placed on the pump's force flange and vacuum manometer was placed to the suction pipe. Pump's suction flange diameter, force flange diameter, impellor diameter, required working flow rate and force height values were written to test report. Test was started in a way that force valve was barely open.

In the same flow rate values, pump suction will be difficult when the valve is tightened. At the same time, the particles which will cause cavitation starts to knock. According to data during the test, although flow rate decreases after a specific value, the value which can be seen on the manometer stays the same. However it was seen that actually the more flow rate decreases, the higher the force force height gets. It was realized that that's reason is because of pressure difference. Because serious changes on the vacuum manometer was observed. It was seen that the reason was caused by the reactions when the pump is exposed to cavitation.

Inline Type Centrifugal Pump		CAVITATION TEST OF PUMP			
PUMP		ENGINE		MEASUREMENT OF ELECTRONIC FLOW	
Pump Type	INM 125-315	Mark ....:	WAT		
Inlet Flange	125 mm	Power ....:	30,0 KW	Z2-Z1	0,00 m
Outlet Flanşı	125 mm	Rotation.............:	1475		
Impeller Diameter	307 mm	U ....:	380 Volt	DYNAMOMETRY :	KWm.
Flow	175,0 m3/h	I ....:	55,7 Amper	MULTIMETRE	480
Pump Head Hm	30,0 m	Cos F ....:	0,85		4
Altitude:160 m	0,99453 bar	h engine ....:	0,96		100
Absolute Pressure Rotation of Impeller for Cavitation			5000,0 kPa		

MEASUREMENT OF HYDRAULİC						NPSH					Real Value	
Array	Speed	Q	He	Hb	Hm	Ve2/2g	T	Pb	Hb	NPSH	Q	Hm
No	(d/dak)	m3/h	m	Bar	m	m	C	Bar	m	m	m3/h	m
1	1470	250,0	-5,4	1,70	22,7	1,63	32,00	0,049	0,50	5,88	250,00	22,74
2	1478	225,0	-6,20	1,95	26,1	1,32	31,50	0,041	0,42	4,84	225,00	26,09
3	1481	200,0	-6,6	2,10	28,0	1,04	31,00	0,046	0,46	4,12	200,00	28,02
4	1482	175,0	-7,0	2,25	30,0	0,80	29,50	0,041	0,42	3,52	175,00	29,95
5	1484	150,0	-7,2	2,35	31,2	0,59	28,00	0,049	0,50	3,03	150,00	31,17
6	1483	125,0	-7,5	2,40	32,0	0,41	28,00	0,041	0,42	2,63	125,00	31,98
7	1487	100,0	-7,8	2,40	32,3	0,26	27,00	0,044	0,45	2,16	100,00	32,28
8	1487	75,0	-8,0	2,40	32,5	0,15	27,00	0,046	0,47	1,82	75,00	32,48
9	1487	50,0	-8,2	2,40	32,7	0,07	26,00	0,048	0,49	1,52	50,00	32,68
10	1489	0,0	-8,5	2,40	33,0	0,00	25,00	0,049	0,50	1,14	0,00	32,98

Figure 7. Pump cavitation test report.

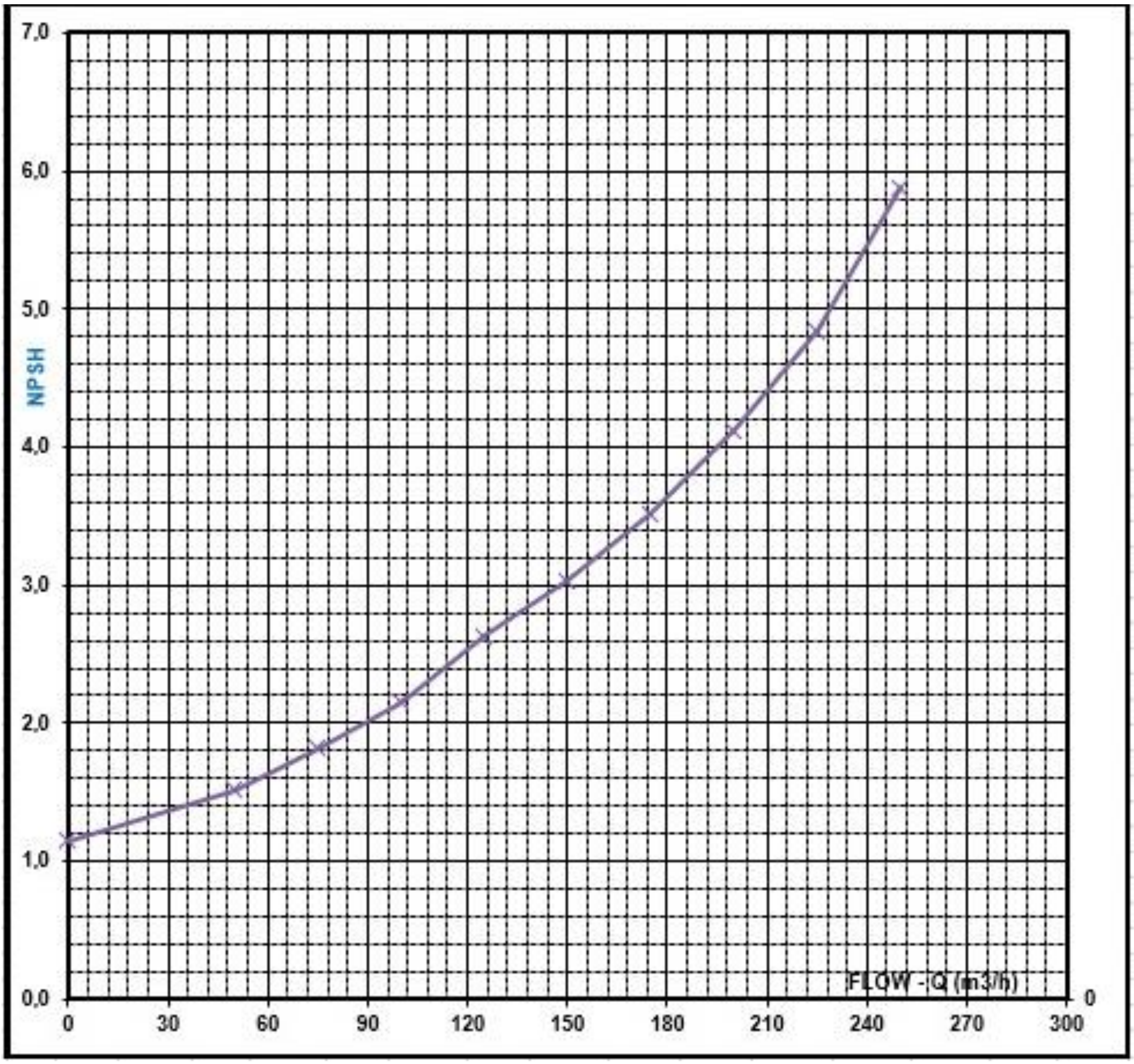

Figure 8. NPSH cavitation test chart.

Lets analyze Inline type centrifuge pump impellor, performance and cavitation test result values with ANSYS analysis. Flow entrance from the impellor's suction area and flow exit from the force area were determined. Rotation cycle of the impellor was determined as 1475 d/d. Flow rate into the impellor was adjusted as 48.6 kg/sec. Pressure in the suction line was written as 99453 Pa. Water was chosen as flow and 25° C was chosen for temperature. Analysis result absolute pressure rotation graphic can be seen in figure 9. According to this result it can be seen that there is no damage on pump impeller and there is no damage for 175m3/s which is the working flow rate. When the flow rate value is 69.4 kg/s a sudden damage occures on the impeller. Cavitation beginning absolute pressure which is mentioned in PSP is 5000 kP. It can be seen that absolute pressure rate is 1.883e+006 in 69.4 kg/s or 249.84 m3/s flow rate value in ANSYS test. In other words, it was seen that PSP result is 5000 kPa, the result of ANSYS is 5118 kPa. The results shows the concord between ANSYS result and PSP values. ANSYS cavitation test, flow rate values are examined in 65 kg/s, 69.4 kg/s, 85 kg/s, 100 kg/s and 120 kg/s respectively. The results for these values can be seen in figure 6.9-13. It can be seen that damages because of cavitation on impellers are symmetrical as flow rate values become higher.

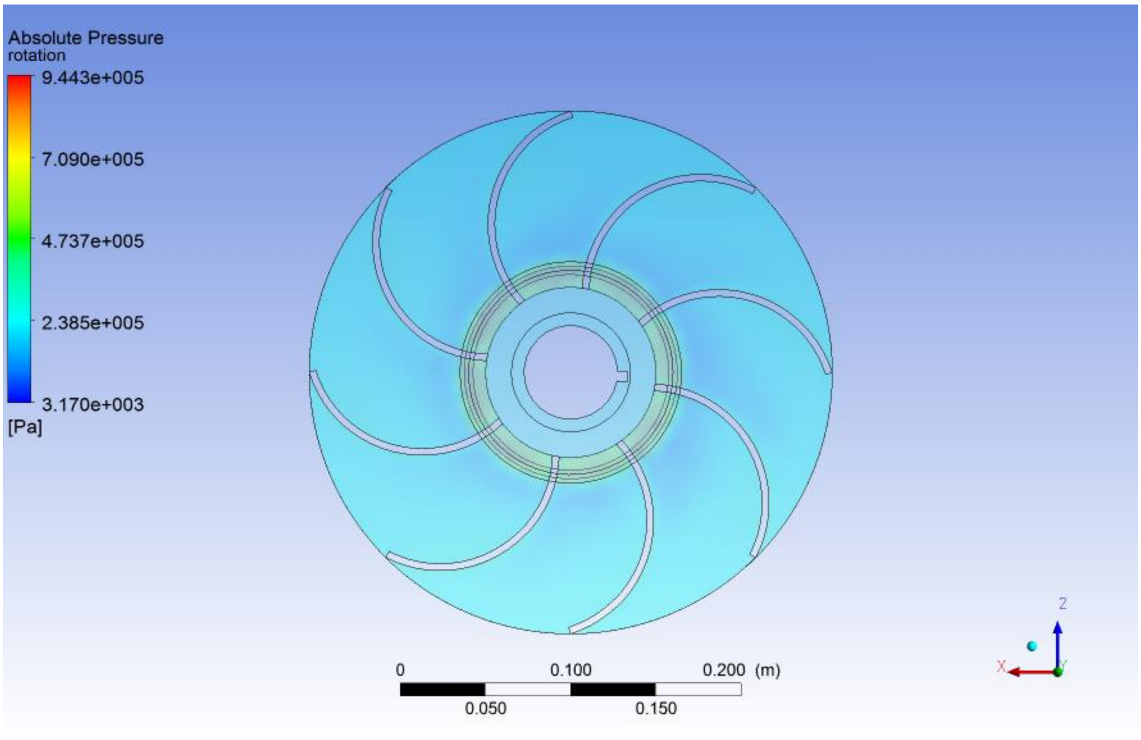

Figure 9. ANSYS analysis of inline impeller for 48 kg/s.

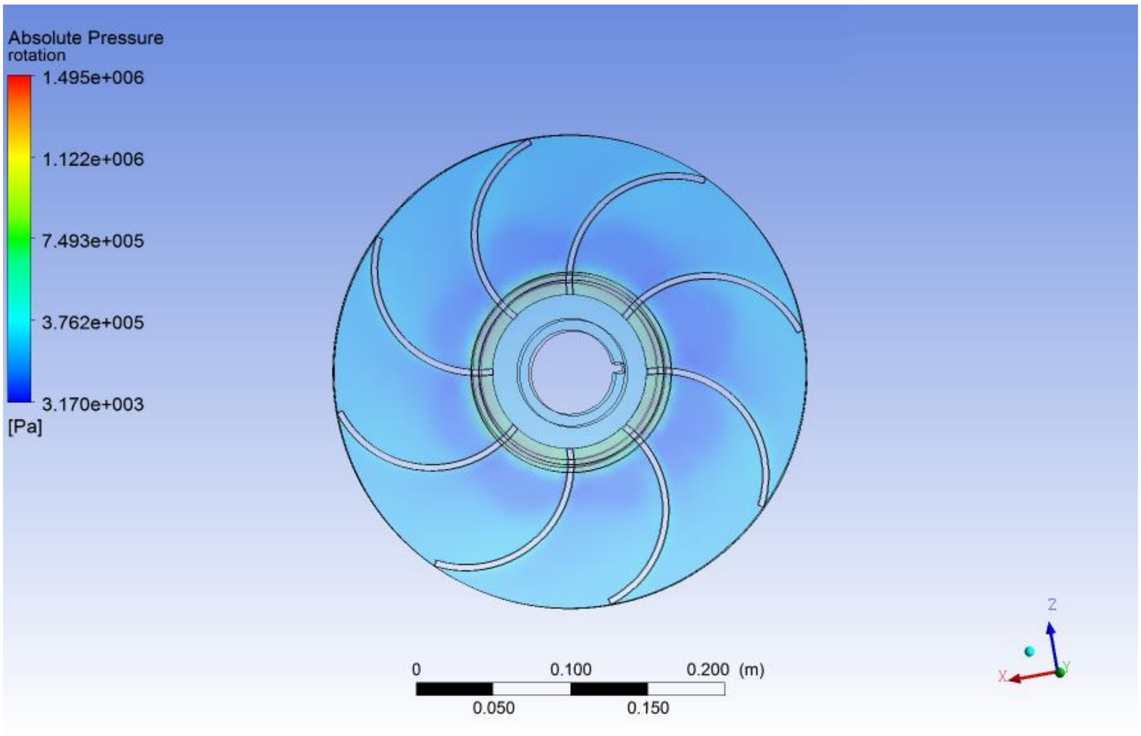

Figure 10. ANSYS analysis of inline impeller for 65 kg/s.

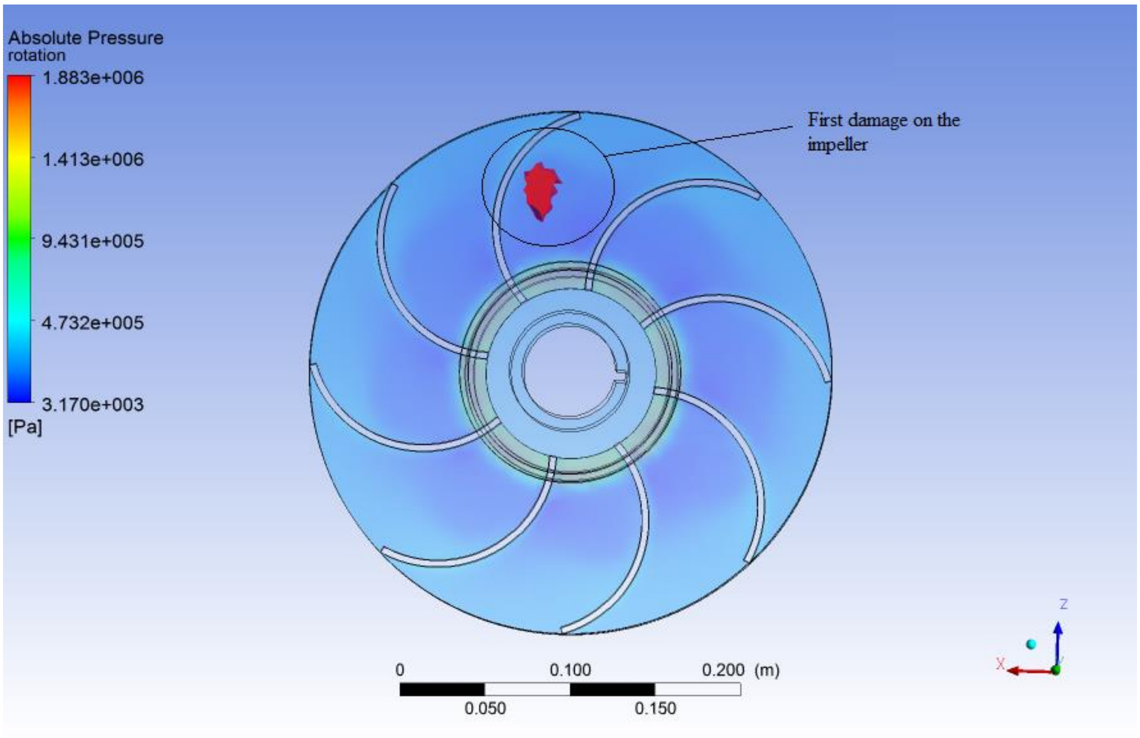

Figure 11. ANSYS analysis of inline impeller for 69.4 kg/s.

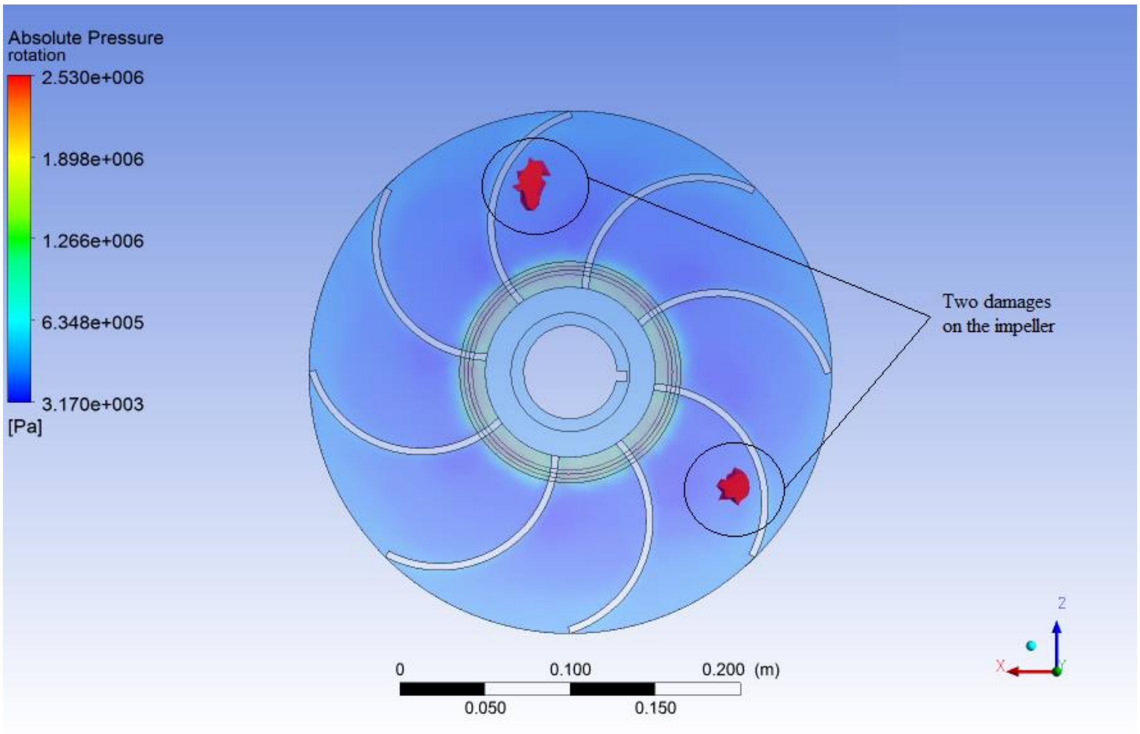

Figure 12. ANSYS analysis of inline impeller for 85 kg/s.

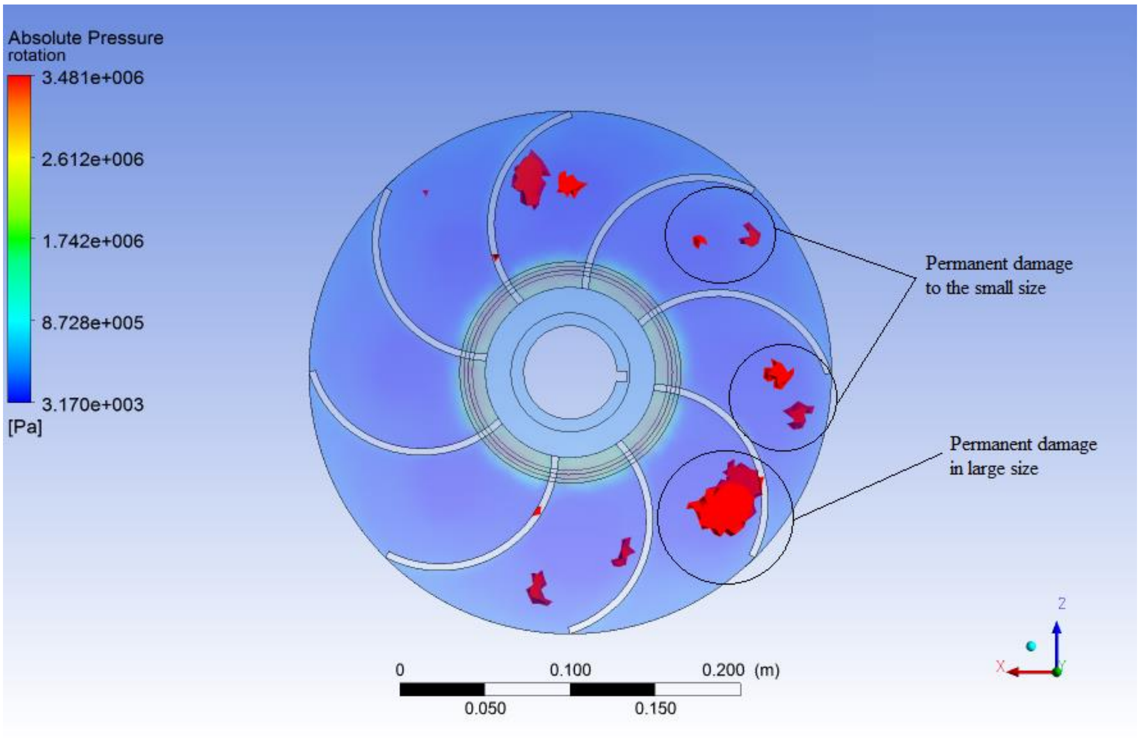

Figure 13. ANSYS analysis of inline impeller for 100 kg/s.

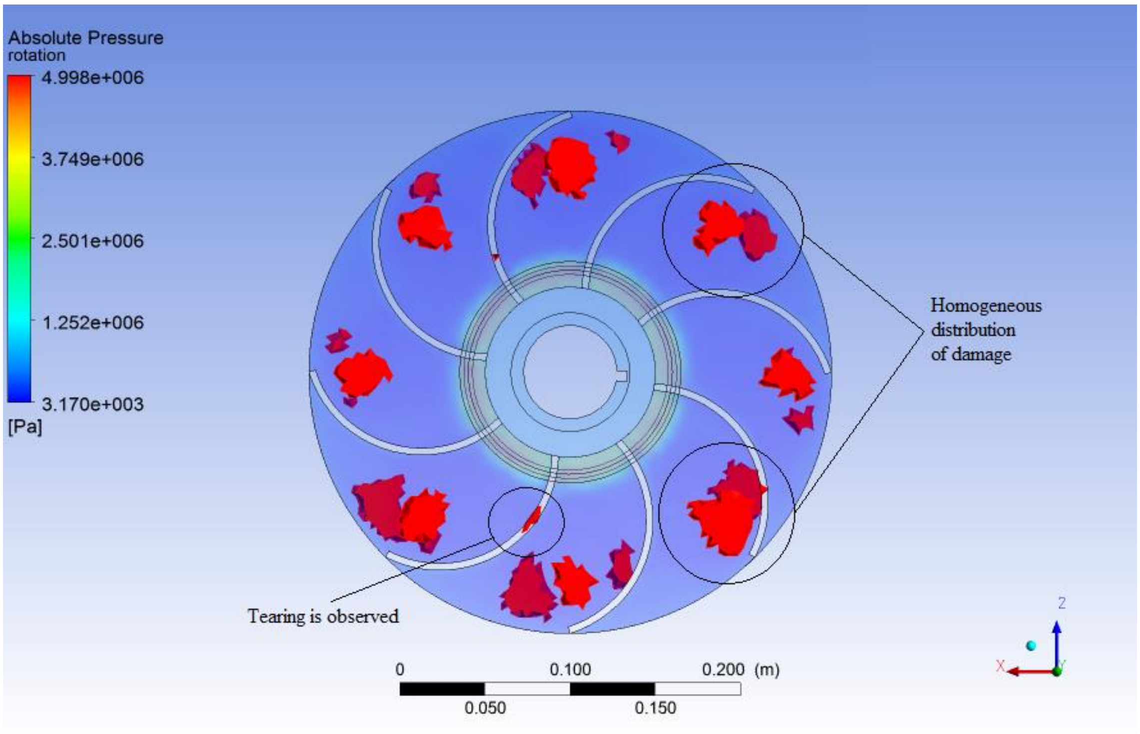

Figure 14. ANSYS analysis of inline impeller for 100 kg/s

5. Conclusions

When we look at the results of the test, it can be seen that as the flow rate becomes lower, speed becomes faster. When the flow rate is reduced, it can be seen that force height becomes higher. Even if the values on the vacuum manometer rise, the values on the manometer rise more and rise on the real force height is observed. As the flow rate rises, the power quantity being used by the motor rises. That's why motor kW, which is suitable for 1.5 times more of ideal flow rate value, was chosen. Otherwise, there could be ignition in the motor in time. As the power being used by the motor rises, ampere rating also rises. Figure 4 shows that the highest productivity gained in ideal working conditions among test values. When the installation is closed by reducing the flow rate on the force flange, the installation becomes hot. The heat becomes more if the pump works in closed loop for a long time. As the force valve of the pump is reduced, the power will reduce sharply because of the fact that there will be less flow through the installation. But this doesn't provide the most productive working condition. The reason is that; it can be proved that the factors effecting the productivity are not only stable to the used power but also the pump productivity is the ratio of the hydrolic power transmitted to the fluid nettably to shaft power. As NPSH value rises, cavitation sensibility and the heat rise. It can be seen in figure 8 that as the flow rate rises, NPSH value also rises. Temperature differences at the beginning of the test and for each flow rate value can be seen in figure 7. During the test values for 10 different flow rate have been obtained. As a result of these values, it has been observed that kinetic energy rises as the flow rate rises. Decrease in the electric motor cycle has been determined as the flow rate rises. This is because the motor slogs on high speed. 14 cycles per minute between maximum flow rate and closed flow rate on force flange have been seen. On NPSH graphic formed according to the test results for 10 different conditions, as the flow rate rises a regular rise has been observed. At high points in the graphic, the pump is more sensitive to the cavitation. That's why, the pump shouldn't be worked with these values for a long time. During cavitation, serious pendulation characteristic can be observed in the pump.

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