

The Damage of Level 7 impeller & lesser Reproducing For the Air Compressor in Company

20000Nm³/h Oxygenerator Line

Bi Chengli Zhu Hongbo

(Equipment Department of The BenXi Steel &Iron Company, 117021, Benxi, Liaoning)

【Abstract】 It is the defect of the design of manufacturer that caused the serious quality problem of the impeller damage of assembled-type boost air compressor of 20000Nm³/h oxygenerator put into production by bengang in 2002 during one year. In the case of the long cycle time of manufacturing the spare part , adopting the reproducing process of lesser fused-cover has repaired the impeller which was thought to be irrecoverable by the foreigner specialists in order to ensure the production of my company.

【Key Words】 oxygenerator; impeller; crack; resonance; lesser reproducing

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1 General

Our company put into production the assembled-type boost air compressor of 20000Nm³/h oxygenerator. It consists of air compressor and booster. It has 7 levels compress. During the work ,the main drive motor pass the torque to the big gear of the air compressor, then the big gear drives the four small gears. It may pass the different speeds to all levels impeller of the air compressor. The driven impeller of the air compressor sucks air from the inlet and speeds up the media according to the outlet direction of the impeller rotary and transforms the movable energy into pressure inside all levels space. Therefore, it realizes the purpose of pressure the air.

The level6 and level7 of air compressor are in the same shaft and driven by the same small gear, so they have the same rotary speed. The rotary speed of air compressor is 1491rpm, but the rotary speed of level6 and level7 of air compressor is 31650rpm. During the running, the relative parameters of level 6 and level 7 of air compressor is the below chart.

Table 1
The Relative Parameters of Level6 and Level7 of Air Compressor

level	Suck	Charge	Suck	Charge	Vibration value			Bearing temperature		
	pressur e (MPa)	pressure (MPa)	temperatur e (°C)	temperature (°C)	(μm)	normal	alarm	linkage	normal	alarm
六	2.0	3.38	32	106	7~8	32	44	89	105	115

The vibration problem of level 6 and level 7 of air compressor has lasted long time. German supplier put off the date of delivery for many times before the arrival of the air compressor because the value of the vibration value of level 6 and level 7 fail in the test before ex-factory. Supplier had to redone it. The air compressor after redone pass the test reluctantly. When the pressure of the running raise to 3.0 at first time, the level 6 of air compressor produces vibration and the vibration has been adding with the adding of the load. So is also the level 7. During the test, the supervisor of HYAL had to make the air compressor run by regulating the alarm and interlock in order to ensure the requirement of 20000Nm³/h air compressor running. And in the end the equipment produced eligible Oxygen, Nitrogen and Argon. HYAL supervisors have tested the air compressor on site. The test work hasn't pass because of the vibration problem. In the nearly one year, the vibration of level 6 and level 7 of air compressor has been troubling us. In the most time, the running of air compressor is low load. The outlet of level 7 of air compressor hasn't been reaching the designing pressure and there existing the vibration from time to time. Contractor HYAL and manufacturer MAN GHH BORSIG company have been regarding the problem. They communicates the problem with us by fax or dispatching SV to site and collectes the relative data, analyzes the vibration reason, seeks the method of solving the vibration. Our company has exerted a great deal investigation and documentation collecting work. We expect the hard problem which is affecting the equipment production as soon as possible. At the same time, we create much chance to solve the problem for manufacturer. The manufacturers make conclusion which vibration problem of level 6 and level 7 of air compressor is caused by the design reason through collecting the data of the site and the test of the site. Namely, it is the problem of axial seal and radial seal that caused the airflow disturb among levels. And it made the vibration of level 6 and level 7 of air compressor too much and affected the running. So they make out the detail solution and do the abundant preparation. They transform the configuration type of axial seal and radial seal of level 6 and level 7 impeller of air compressor. They change arc-type impeller axial seal and radial seal into tooth-type seal and make the new axial seal and radial seal of level 6 and level 7. After the change, the vibration disappears when running and the outlet pressure of level 7 of air compressor reaches the design value. At the same time the vibration value of level 6 and level 7 reaches the design demand completely. It runs one month after the axial seal and radial seal of level 6 and level 7 impeller. It has done the clean work to the sprayer #5 line nitrogen tower by schedule. After finishing the clean work for nitrogen tower, the relative engineers start to do the recovery work of the raising pressure for air compressor. During the recovery work, appears the fault of automatic shutoff caused by the vibration of level 6 and level 7 of air compressor.

When the recovery work is doing normally, suddenly the air compressor shut off with automatic linkage because the vibration value of level 7 is high (up to 51μm, at the time the level 6 vibration is 10μm or so), it leads to the automatic linkage shutoff of air compressor. Due to the requirement of the production, finally decide to

restart the air compressor after confirming no problem by the examination of air-separated process and computer major to each system. After the air compressor restarts, the vibration of the level 7 has been high under no-load state. It keeps 39 μ m or so. With the increase of pressure, the vibration has been in the trend of increase. Considering the state, the air compressor is stopped manually. At that moment we doubted whether the probe has problem, we don't find any problem of probe through the detail exam of instrument engineer to air compressor. After that, we restart the air compressor again, but the vibration of level 7 is still high. At last we make a conclusion that the high vibration of level 7 of air compressor is true, we must do divided-part examination to the air compressor through the analysis of the curve drawing of real time sample points to computer process.

2 problem analysis



Fig 1 the gap state of impeller

We find the edge of impeller has a gap of 17 \times 25mm through the divided-part examination of the level 7 impeller outlet side. After that, we do the magnaflux inspection and color-up crack detection to impeller with discussion of the engineers of bengang technology center. We find there are 10 cracks at the backside bottom of impeller. The longest crack is 23mm. All cracks produce at the same side edge of impeller. Its character is it appears in the bottom edge of impeller vane. At first it extends towards radial direction forwards, then at the end it begins to turn. The material near the crack has't deform clearly.

We invited the technical staff of shenyang mainland laser group after the damage of the level 7 impeller of air compressor happened. The specialists think the impeller can be repaired after the datail discussion and demonstration. Once the repair is successful, it will shorten one month project time than it is ordered from Germany, so it will make the loss of my company up to the minimum.

The technical staff have done techinical exchange with mainland company. The mainland company recognize initially that the damage of level 7 impeller may be repaired through the total inspection to the damage degree of level 7 impeller by the mainland company. But it will confirm again after doing limit source analysis and

intensity analysis to the damage of level 7 impeller for the specific case.

If the impeller can be repaired ,it may finish within 7 days . And ensure level 7 impeller after repairing can run three months without any problem. For ensuring the production of my company ,we finally decide to let the mainland company repair the impeller. At the same time they provide the relative parameter documentation.



Fig 2 impeller crack show

About the repair matter of level 7 impeller, MAN GHH BORSIG,the manufacturer of Germany ,does't agree on it. Their opinion is the damaged impeller of level 7 must be carried back their company,then they do the technical identification by themselves to confirm the reason of the level 7 impeller damage. They don't agree to our repair work firmly.And they put forward they aren't in charge of the consequence of our repair work.Considering my company production ,the cycle time manufactured new impeller is above one and a half months and the repair work of impeller done by the mainland company is based on the science.The method which decide to repair the level 7 impeller can solve the urgent demand of my company production.

For ensuring the repair quality of impeller, we do the total identification for the level 7 impeller damaged with the mainland company and chinese science metal research institute. The result of the identification is the following.

2.1. The condition of impeller running

The turbo compressor damaged by impeller is made in Germany. Its type is RG 090 / 03+04—L3, the material of impeller is x4CrNi13—4 martensite type stainless steel.

The condition of impeller running is the following.

Revolution is 31650 rpm/min; the pressure of inlet is 3.5MPa; the pressure of outlet is 6.12 MPa; flux is 25100~26000m³/h; the temperature of inlet is 37°C (43°C alarm) the temperature of outlet is 106°C (123°C shutoff) the oscillate value is 30μm alarm; 42μm shut off; the medium is air. The time of the total running is more than 8000 hours.The level 7 impeller damage,its damage process is the following.The normal oscillate value of the level 7 rotor is 7~8μm, but the oscillate value during the actual running has been keeping 30μm.It suddenly shuts off after several days,the

oscillate value recorded is 50 μ m.

2.2 inspection and analysis

2.2.1 the standard chemical composition of impeller ,see list 2

Table 2 the chemical composition of impeller (%)

C	Si	Mn	P	S	Cr	Ni	Mo	N
≤0.05	≤0.60	≤1.00	≤0.030	≤0.015	12.5/14.0	3.5/4.5	0.40/0.70	≤0.020

2.2.2 the mechanics character and heat treatment process see list 3

Table 3 the mechanics character and heat treatment process

name	σ_b (MPa)	$\sigma_{0.2}$ (MPa)	σ_5 (%)	A_k (J)	hardnessHBS	determinant
X4CrNi13-4	780/980	≥685	≥17	≥90	290/301	DIN
heat treatment process	560-600□ temper					DIN

2.2.3 outline inspection

There are no impact,scratch and corrupt on the front and hind cover of impeller and vane. It proves the damage of impeller is none of the impact and corrupt.There are 10 different size cracks at the edge root of the front cover of impeller found by color- probe inspection ,the longest one is 23mm. All cracks produce at the same side of impeller. There is the grind mark on outside surface of the cover. It doesn't look like during the usage. It maybe be formed during decreasing the weight when commissioning the dynamic balance.

The crack character on the front cover is the crack lies in the side root of the vane. It extends forward along radial direction at the beginning ,it starts turn at the end . The material near the crack does't have clear deform. It proves the front cover is brittleness rupture. Judged from the position of crack formed, quantity and outline character,the crack of the front cover is syntony fatigue crack. There is a crack block of 17×25mm at the edge of the hind cover of impeller.

2.2.4 the analysis of fracture

The fracture surface of the hind cover edge of impeller show arc shape.The crack extends forward at the form of being vertical on the surface . The crack source produces on the inside surface at 9mm from the edge. The crack source colour is black. It proves that is metallurgy fracture or manufactured fracture. The crack source include two parts . One is flat, and the other is rough.There is a clear crack extend pause line on the flat fracture area.It proves that is fatigue fracture area. The rough fracture is instantaneous over-load fracture produced by the remain area of impeller vane which can't endure load .The area of fatigue fracture area is larger. The area of the end break is smaller. It proves the work load endured by impeller is smaller. The

material near the fracture is no clear deform. It proves the impeller is brittleness rupture. The reason analysis of fracture is the following.

The material of impeller is Germany brand x4CrNi13—4 martensite type stainless steel. We can't find the relative number in Chinese standard. Judged from the hardness, the impeller has been done in 560~600°C temper, its metallography should be temper sorbite.

At the same time the edge of the front cover of impeller produce 10 cracks. Judged from this, these crack is syntony fatigue crack. The character of the syntony fatigue crack produce many cracks on the syntony band at one time. If one crack extend leading, the others cracks won't stop extent until fracture. The damage phenomenon of impeller accord with the above rule. The revolution speed of impeller is 31650rpm/min, It has run for one year before damage. Proved from this, the crack produced is none of impeller design. It is caused by over-limit oscillate value.

The crack block of the hind cover edge of impeller is fatigue fracture. The manufactured defect inside the cover is the main reason produced the fatigue fracture.

2.2.5 conclusion

The crack on the front cover edge of level 7 impeller of Centrifugal compressor is syntony fatigue crack. The strong vibration is the main reason of producing syntony fatigue crack when running. The oscillate source of the compressor is caused by the airflow disturbance inside the compressoe body. Its main reason is the design cause of the radial seal. Later manufacturers adopt our suggestion, they will change the 32 radial seal, the channel which prevent airflow disturbance into 27, so it eliminate the oscillate source completely. The crack block of the hind cover edge of impeller is fatigue fracture. The metallurgy or manufacture defect existed in material is the main reason of producing fatigue fracture.

3 To constitute the repair solution and repair result of impeller

3.1 For insuring the repair quality of level 7 impeller, we do technique communion many times with the mainland company. At last we confirm a repair solution mutually.

- 3.1.1 Make step shaft, measuring the jump dimension of two vane of impeller and the each position dimension of all body.
- 3.1.2 Clear crack, eliminate slope and clear crack block place.
- 3.1.3 Intensity calculate and life-span evaluation; invalidation reason analysis;
- 3.1.4 Laser melt 10 cracks and break block.
- 3.1.5 Trim skin pass, recover original dimension, polishing;
- 3.1.6 Probe detect inside defect;
- 3.1.7 Finishing grind inspection, measuring skipping value;
- 3.1.8 Vacuum temper treatment;
- 3.1.9 X-ray detect;
- 3.1.10 The balance test to the repaired level 7 impeller;
- 3.1.11 Detect frequency to the repaired level 7 impeller;

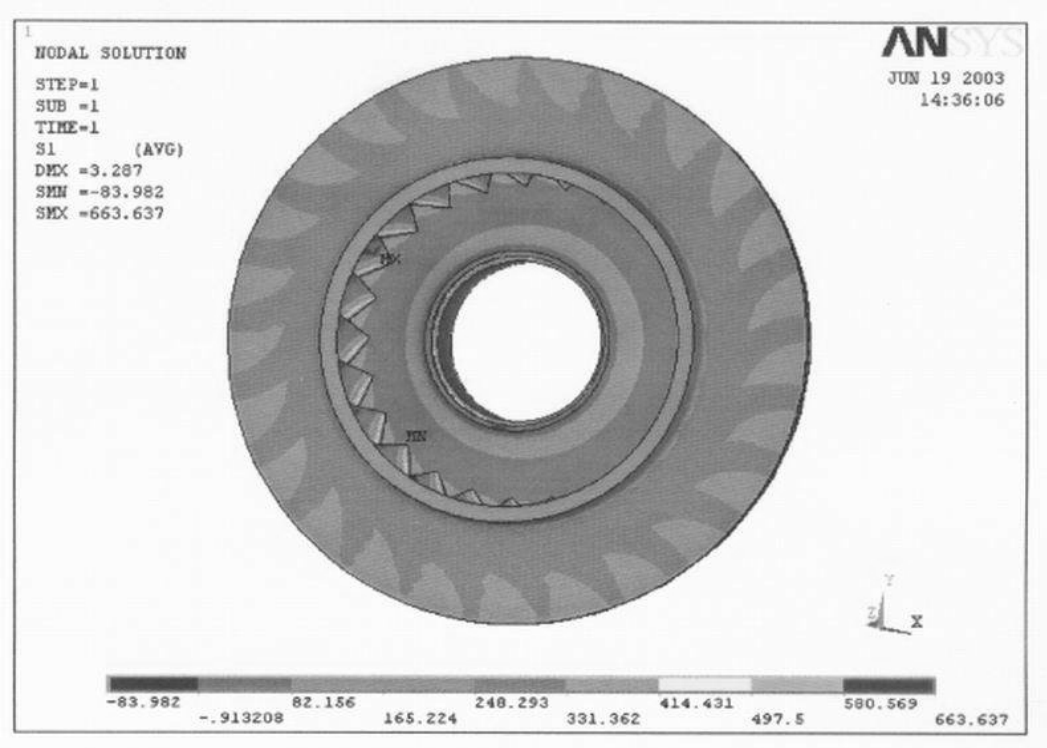


Fig 3 computer strength calculation model

3.2 laser reproducing technology

Laser technology is one of four great inventions of being eponymous with atomic energy ,semi-conductor and computer in the 20th century. Since laser enter machine field as a strong,non-contact and clean heat souce, it has solved a lot of problem which can't machine and hard machine by using the normal method .It greatly enhances the production efficiency and machining quality. It is called the machining measure of the future manufacturing system.

Laser reproducing technology mainly aim at damnification and scrap product up to physical life-span,economy life-span and technical life –span.On the base of the damnification analysis and lifespan evaluation,regard the damnification and scrap parts as reproducing blank. The laser reproducing mainly aims at the damnification and scrap product up to phycial life-span,ecomonical life-span and technical life –span. On the basis of the invalidation analysis and life-span evaluation,regarding the damnification and scrap part with remaining life-span as the reproducing blank and adoping the technology of the advanced laser fusion ,laser alloy ,laser molding etc to do machine in order to make the quality and character reach or exceed the new product.

The laser fusion is the technical foundation of laser reproducing.The laser fusion technology is putting choosen coating material on the body surface with different filling mode and make alloy power and surface machined instant fuse completely through the character which the large power laser beam get together energy high ,then forming compact coating which has the lower dilution factor and base body

metallurgy combination .Thereby improving remarkably the process method of the friction,anticorrosion,heat-resistant,antioxidation and electric character etc.The character is the following.

3.2.1 laser fusion coating and base are metallurgy combination .The combination intensity is less than the 90% of base material.

3.2. 2 The part base material only fuse on the surface during laser casting machine,the fusion layer 0.05~0.1mm.The base influence area heated is smaller, usually in the scope of 0.1~0.2mm because the laser heating-up speed and cooling speed are very fast.

3.2.3 The base temperature during the machine is usually less than 80°C.It doesn't produce thermal deform basically after machining.

3.2.4 The controllability of laser casting technology is good.It can realize automatic control.

3.2.5 The laser fusion coating and base don't have the defects of roarse casting tissue and the fusion coating layer and its interface tissue are compact,thin crystal,no-hole,no-lard,no-crack etc.

3.2.6 The laser fusion casting layer is grade fuction material consisted of bottom layer,middle layer and furface layer. The bottom layer has the character of high soakage and high combination intensity;the surface layer has the character of antibrushing, antifriction ,anti-corrosion and anti-high temperature. Thereby make the equipment after repairing has guarantee much more on the safety and usage.

3.2.7 The laser fusion casting technology may copy the repairing and manufacturing part at random.The thickness of the fusion layer may reach schedule dimension requirement accoding to demand.

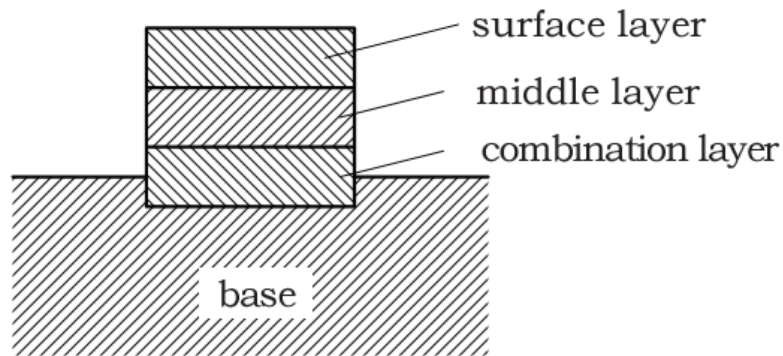


Fig 4 laser fusion coating complex layer tissue schematic

3.3 the repairing of impeller

The impeller is installed on the shaft by heat mode. The impeller heat installation is not only the demand for passing torque but also avoiding loose demand under the high speed rotation. What's more, the impeller can also produce the loose of impeller because of the centrifugal stress ,therefore produce eccentricity and imbalance.The close-mode impeller be made of one wheel-disc,several vanes and one wheel cover.The vane is hind-curly;the vane is milling on wheel disc,then will weld the wheel cover from inner. As for the vane is milled from wheel disc or wheel

cover, it depends on the shape of the impeller, therefore it depends on whether the welding rod can stretch into the vane channel or not.

Adopting the method of exterior laser welding because of the vane channel narrow and inner welding hard. Namely, open some shallow groove similar to its shape at the damage place of wheel cover and crack place. Filling full the welding material and make it fuse, so will fuse damage part and crack part together. Therefore finishing the welding process.

Using heat treatment to eliminate the stress after finishing welding process; probe at the welding part; quench and annealing; finally do machine.

As for the structure design of impeller, we must consider the impeller is the part endured the biggest stress. Reducing the step of compressor can make the most speed of vane top higher and higher, so the stress is higher and higher. The distribution of the stress in the parts of impeller are different. Obviously, the specific distribution form of the stress has relation with the impeller form. Be able to analyze well the stress distribution in the impeller through limit unit way (F.E.M.). Therefore obtain the dynamic character of impeller (inherent frequency and its relative mode.)

The stress value is proportional to the square of speed ratio. The maximum stress appear in over-speed experiment (the speed is the 115% of the largest continuous revolution). Especially should pay attention to the stress area of vane work root part. When designing and machine the each surface of impeller. And as a principal, should especially avoid the concentration of stress and especially consider thickness, key channel and rounding in the process of the manufacture of impeller. When choosing material and heat treatment, should consider the stress caused by eccentricity and the impeller work surrounding.

For ensuring the weld of vane repairing part better, using the welding material of the high mechanical performance and low carbon. The material of impeller is x4CrNi13—4 martensite type stainless steel. So the welding material should be chosen the same or close material with original material, in fact the welding material and the original material are different.

When the steel products keep in sensitized temperature, carbide will be able to separate out a great deal in the process of quench and the process of welding heat. The amount of separating out depends on the content of carbon. At the same time it also has the relation with the quench process after heat treatment and the temperature and time during welding and heat. Adopting the laser welding to avoid the whole deform caused by over-heat impeller. This is extremely important for the good or bad of final impeller repairing quality.

3.4 the dynamic balance of rotor

3.4.1 Alignment of impeller

First of all, install impeller to balance equipment, then install the whole unit to balance machine. Turning the unit by hand to confirm the right installation. Measuring the eccentricity on the external diameter (the maximum value is 0.02mm)

3.4.2 Balance impeller under higher speed

According the weight of impeller, make balance speed and the limit speed of balance machine fit, finally make final imbalance amount inside the allowable scope

specified in API 617. Then, impeller must do overspeed experiment.

3.4.3 Install the impeller to the shaft of two linkers which is used for balancing impeller, then assemble shaft to vertical over-speed unit. After tripping of over-speed unit set tripping revolution, do over-speed experiment and keep the rev about 10min. The over-speed is consistent to the revolution specified in rules. Yet the tripping rev is 2% higher than the over-speed rev.

3.4.4 vacuum degree should keep the level which absolute pressure is under 1Torr. The vibration speed on turbomachine should be less than 6mm/s.

3.4.5 Finally record the test value, then impeller must do through the color inspection of the penetrating fluid and install to the shaft.

3.4.6 rotor

Install shaft to balancer and put on the journal bearing, then cooperate assistant half-key. Using filling to fill up the clearance of shaft end lockring, and start the balance sequence. The choice of balance speed refer to the character of the machine, and adopt the balance accuracy required API617(OCT.1973 edition). Then, after installing the impeller done, use the method which eliminate the material of hub and wheel cover to balance the rotor and eliminate the above odd weight. Using the method of drilling a hole on the ring to balance the seal ring. And install thrust bearing on the shaft and use the method of cutting excircle to balance bead flange. As the final inspection, rotate the connection head on the balancer to 180° and examine the balance situation. The above balance method is based on the basic balance rule of the flexibility rotor. For preventing produce inner torque when install the rotor, the rotor is balanced in the different period. Namely all rotors are balance after installing the every part (impeller, separate-ring etc.)

3.5 measuring frequency test

After finishing the work of repairing the impeller, the technical group and shenyang 606 research institute do measuring frequency lab of level 7 impeller together. The result of the measuring is the following.

3.5.1 lab purpose

According to the requirement of the BenXi Steel & Iron Company and mainland company, do measuring frequency to the BenXi Steel & Iron Company RG090 / 03+04—L3 the level 7 impeller of compressor.

3.5.2 lab part

The lab part is the BenXi Steel & Iron Company RG090 / 03+04—L3 level 7 impeller compressor repaired by mainland company. The impeller ever has a lot of cracks and failure.

3.5.3 lab method

Adopting knock. Using heavy hammer to knock. Acceleration sensor pickup respond signal. Using CF—920 analyser to analyze carefully and get the inherent frequency of all steps of the impeller.

3.6 the result of lab

The purpose of doing the dynamic balance lab and measure frequency after finish repairing the impeller is to ensure the impeller repaired to reach the lower normal

standard . The later running result also prove the measuring result is true and credibility.

3.7 the result of repairing

It took 7 days to finish the repairing work of level 7 impeller through the technical group effort. After it ,start running on May11,2003 and one time succeed .All technical target reach the rules demand and safely run to the new spare part arrival.

4 The signification of repairing the level 7 impeller

The repairing of the impeller is laser reproducing process on the high speed rotation equipment with a challenging attempt .The success of repairing show the laser reproducing of our country has reached a ripe period. And also satisfy the demand of bengang production and create the great economic benefit.

4.1 direct benefit

Table 4 the direct calculate chart of repairing

name	Yield per unit	Running time (h)	subtotal	Price per unit	value (ten thousand)
O ₂	18000 m ³ /h	760	1368 ten thousandm ³	0.40yuan/ m ³	547.2
N ₂	20000 m ³ /h	760	1520ten thousand m ³	0.35yuan/ m ³	532.0
Lar	0.7625 m ³ /h	760	579.5 m ³	4000yuan/ m ³	231.8
LO ₂	1.25 m ³ /h	760	950 m ³	900yuan/ m ³	85.5
LN ₂	0.54375 m ³ /h	760	413.25 m ³	900yuan/ m ³	37.2
power-consumption	11000kw	820	902 kwh	0.40yuan/ kwh	-360.8
Water-consumption	80 t/h	820	65600t	3yuan/t	-19.7
total					1053.2

Reducr power –consumption,complementary water (industrial water) ,benefit is 1053.2 ten thousand yuan.

4.2 indirect benefit

According to the comparison of daily production ,the yield add 508t/d when the impeller runs after repairing 508t/d, 31.6 days raise the yield to 1.6ten thousand ton(costprice:1800yuan/ton,the sale price 3100yuan/ton , benefit according to 1000yuan /ton calculation), raise production value 4960 ten thousand yuan, benefit raised 1600 ten thousand yuan.

4.3 safety benefit and other

Due to use the machine,make the safety production of company to obtain ensurance .Its signification is great. At the same time there will existed the lack of oxygen,nitrogen and argon ,it will restrict the production of the other product and breed of company and produce the relative outsourcing charge.