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Increase of capacity by 35% and efficiency raise of the technological qir centrifugal compressor 101J in ammonia production

ANDREY SEMAKOV, VASILIY EVDOKIMOV, ANATOLIY REPRINTCEV, ALEKSANDR LIUBIMOV

Entechmach RPC LLC

Saint-Petersburg, Russian Federation

The paper presents actual example of centrifugal compressor modernization at large-capacity ammonia production site in Russia. In particular, a project to modernize, at minimum cost, the 101J air compressor to raise its capacity from 1,360 to 1950 tons of ammonia per day and to reduce its specific energy consumption is considered.

INTRODUCTION

The large-capacity ammonia production plants in Russia and the CIS that were constructed in the 1970s were equipped with turbocompressor units originally designed for a capacity of 1360 tons of ammonia per day. These production processes were based on the technology of Toyo Engineering (TEC) of Japan or that of the Soviet State Institute of Nitrogen Industry (GIAP). The turbocompressors installed in these plants were built by such reputable machinery companies as Mitsubishi Heavy Industries, Dresser-Rand, Hitachi, Fuji and Nuovo Pignone, Nevsky (Saint-Petersburg) and Kazansky Plants.

As time went by it became desirable to expand these ammonia plants to a target capacity of 1700-1950 t/d. This was far beyond the design capability of the original turbocompressors: an increment of this size could not be accommodated merely by running them faster because their efficiency drops off on account of aerodynamic effects and the risk of damage reduces their reliability. In any case, the drive turbines did not meet latter-day standards of energy-efficiency (= steam consumption).

To replace these compressors with new ones would have been prohibitively expensive, so it was decided to modernize the existing machines' flow parts. The following machines are turbocompressors: process air (101J), synthesis gas (103J), natural gas (102J) and ammonia (105J).

Entechmach RPC has already previously done modernizations of the 101J, 102J, 103J and 105J centrifugal compressors going along with notable prime cost and operational specific energy consumption reduction.

ORIGINAL 1360-T/D AIR COMPRESSOR

As an example let us consider the basic points of 101J air compressor modernization. This machine was originally designed for an inlet pressure of 0.97 MPa and a discharge pressure of 3.6 MPa. The volumetric suction capacity at STP (0°C, 0.1MPa) is 52,000 Nm³/h. The compressor has two cases: low-pressure (LPC) and high-pressure (HPC) cases. There are four sections (Fig. 1). All stages originally are implemented with vaneless diffusers. The drive is a steam turbine with maximum power 11.3 MW.

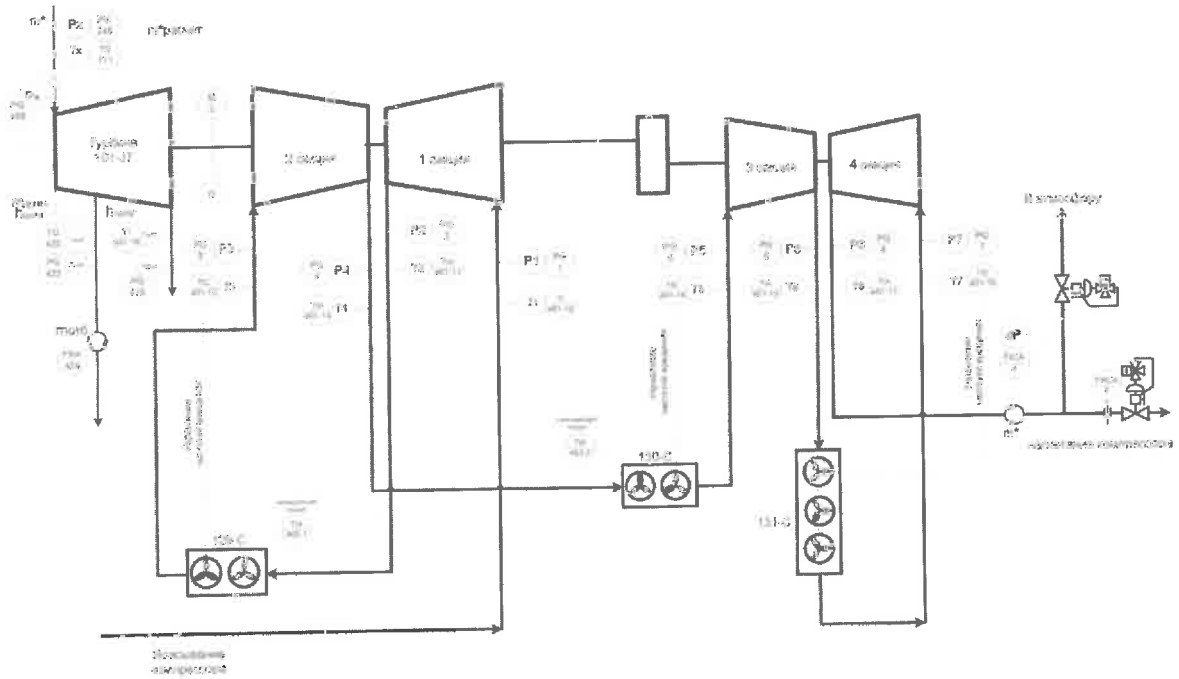

Fig. 1: Air compressor principle scheme

AIR COMPRESSOR MODERNIZATION FOR 1750 T/D AMMONIA PRODUCTION

In 2005, the Russian company **Entechmach RPC LLC** worked on the modernization of an air compressor to raise its capacity to the equivalent of 1700 t/d of ammonia. By the 2014 8 successful modernizations has been completed. The new compressor capacity is 63,000 Nm³/h, 25% higher than the old. A photograph of this air compressor is given in Fig. 2.

Maximum use was made of components of the existing unit: power cases, piping gas lines, valves, lubrication system, etc. In this modernization project the whole LPC and HPC flow part was changed with use of vane diffusers. The new gearbox couple was set.

The intermediate cooler`s sections were changed to new ones with heat exchange surface increased by 25%.

After this in 2012 **Entechmach RPC** implemented a merged (hybrid) modernization for 1800 t/d. In it a HPC with whole new effective flow part from 1950 t/d modernization is used. By the 2014 3 such successful modernizations has been completed.

Fig. 2: Air compressor

In figures 3 and 4 rotors of LPC and HPC of the modernized air compressor 101J (1700 of t/day) are shown.

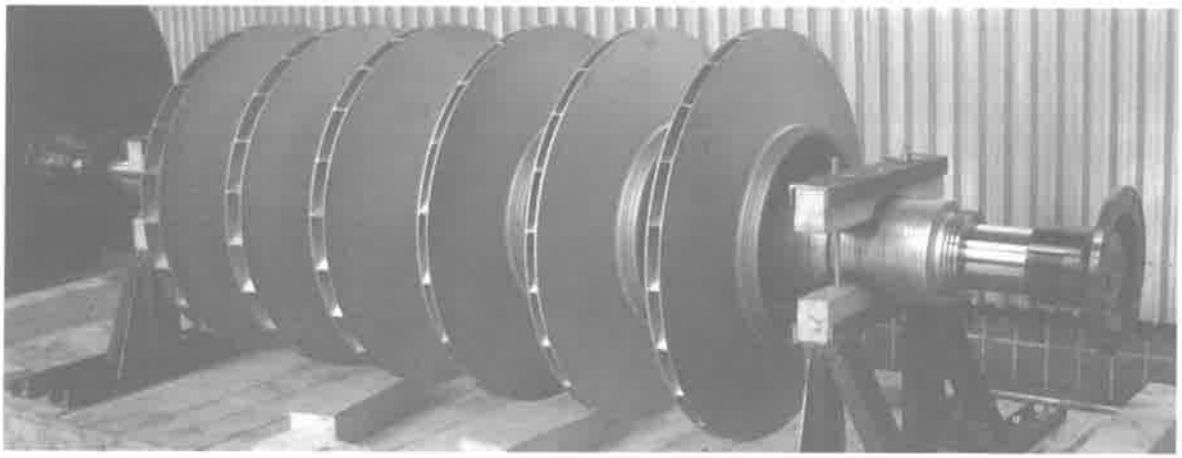

Fig. 3: LPC rotor of the modernized 101J air compressor (1700 of t/day).

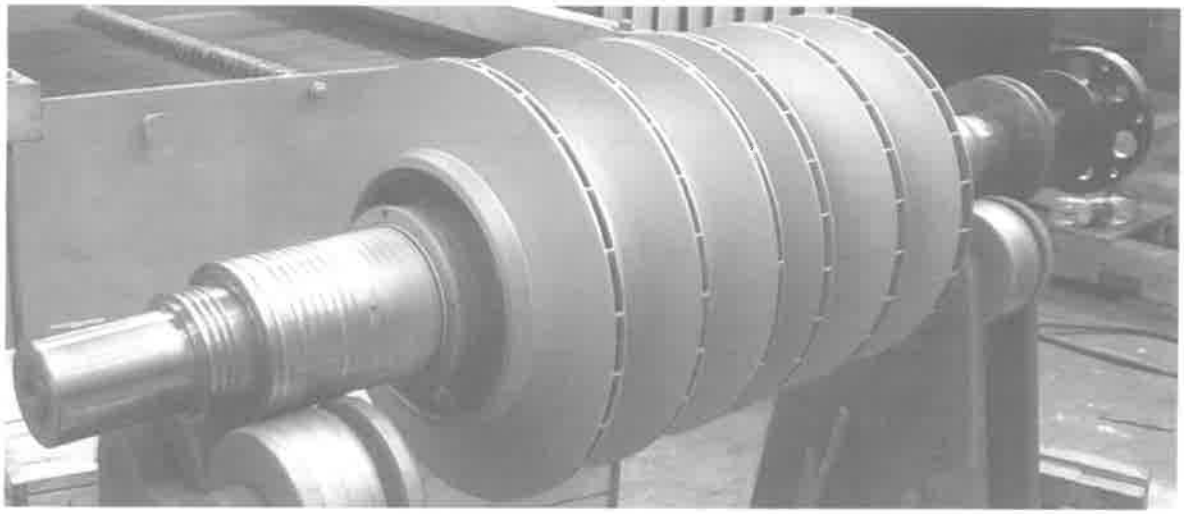

Fig. 4: HPC rotor of the modernized 101J air compressor (1700 of t/day).

AIR COMPRESSOR MODERNIZATION FOR 1950 T/D AMMONIA PRODUCTION

Project description

With the benefit of this experience, in 2011 **Entechmach RPC LLC**, the Polish company **ALSTOM Power** started a joint development project on modernizing compressors and turbines to meet the requirements of the producers for 1950 t/d of ammonia – the "Ammonia 1950" project. The project **was** implemented in 2014.

Such a huge hike in production (more than 35% above the original design value) demands careful study of the changes which need to be made both in the process and in the compressor and turbine. The task of determining just how to accomplish it was carried out by design organizations such as **Ammonia Casale**, which undertook a analysis of the complete process plant in co-operation with the plant operators, whose long-term experience of operating the process and its machinery is invaluable in defining the exact combination of changes in the equipment and in the process conditions that will make it possible to achieve the objectives of the revamp. Figure 5 showes the detailed ovedview of this compressor.

The Ammonia 1950 project is based on several main requirements for the dynamic equipment, namely:

- to adjust the characteristics of the air compressors to attain the target capacity;
- to obtain from the turbine drive the requisite power and speed matching the optimal requirments of the compressor for the minimum steam consumption;
- to ensure continuous uninterrupted and smooth operation within the safety margins specified in the API 612 and API 617 standards;
- to increase the efficiency of compressor and its turbine and thereby reduce the specific energy consumption in the ammonia production.

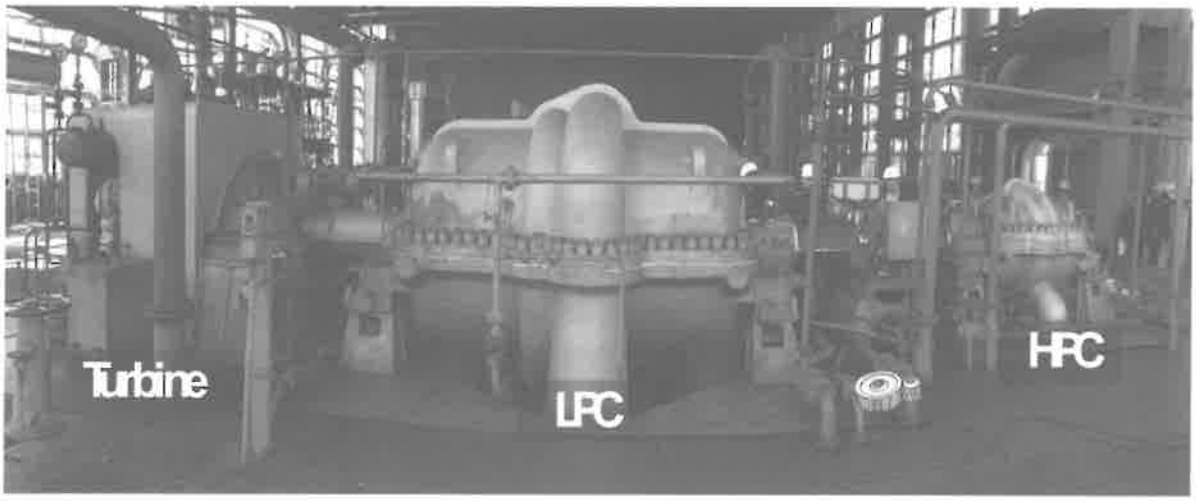

Fig. 5: Air compressor

Experimental database

Entechmach RPC has been able to increase the polytropic efficiency of the modernized compressor's sections and improve the characteristics of the intermediate gas coolers by a sufficient amount to make it possible to achieve the desired 35% increase in ammonia production. Gas flow through the modernized 101J compressor has been streamlined by the use of high-efficiency components such as impellers with cylindrical backward-curved blades and vane diffusers. Compressor stages have been designed using Entechmach's in-house database of information obtained from the company's model rig (Fig. 6).

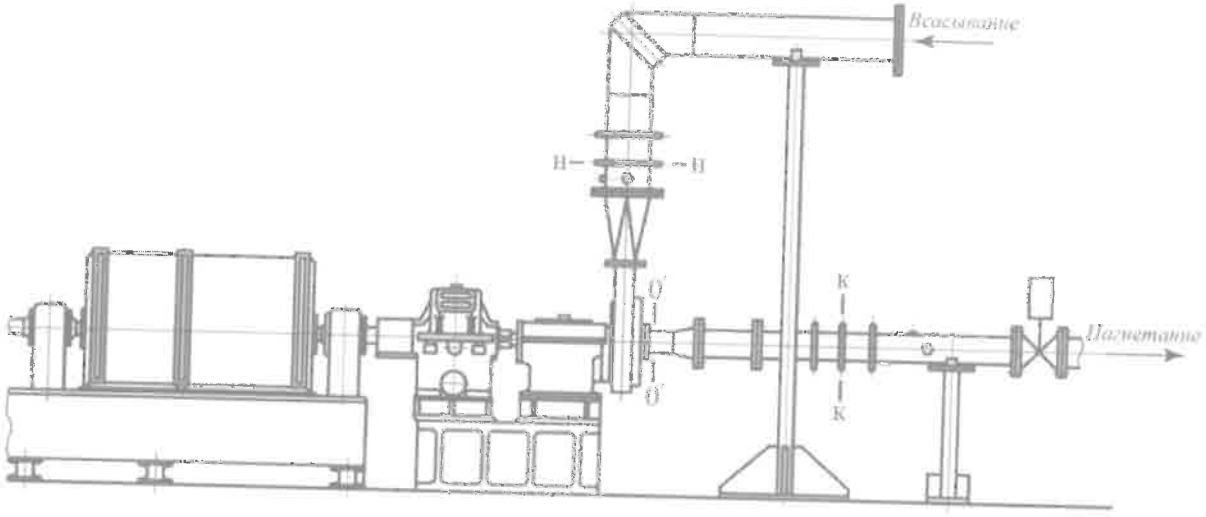

Fig. 6: Model rig for centrifugal compressor stage:
1: Electric motor. 2: Multiplier. 3: Model stage. 4: Suction tube. 5: Pressure line. 6: Diaphragm. 7: Throttle. 8, 10: Sampling tubes for measuring suction and discharge pressure. 9, 11: Chambers for suction and discharge temperature measurement

High-efficiency centrifugal stages with impeller exit angles $\beta_2 = 48°$ and 32° and vane diffusers are used in the modernized 101J compressor. The 5% diffuser airfoil blades have been created after careful experimental research and have a leading blade angle which provides 'bumpless' entry in the normal operation.

CFD analysis

Besides the experimental method of obtaining gas-dynamic characteristics of stages, **Entechmach RPC** also uses the modern finite element method.

Entechmach used the modern finite element method to optimize the flow part of this compressor. The calculations confirmed Entechmach's experimental data on model stages. An example of a calculation of speed distribution in the first stage of the modernized 101J compressor (1950 t/day) with a vane diffuser is shown in Figs 7 and 8. This was worked out in co-operation with **Numeca Russia**. The calculated polytropic efficiency of a stage is equal to 83%, and that is confirmed as well by Entechmach's experimental data on model stages, which gives 82% with reduced geometry close to that one in simulation. The calculation results indicate a high guarantee efficiency for the stages used.

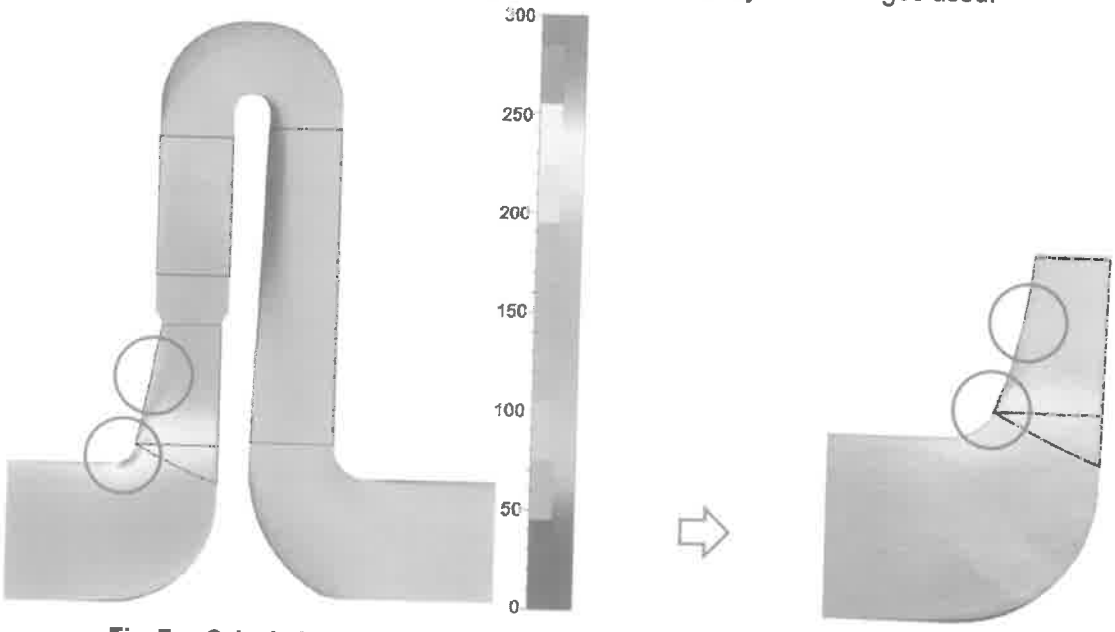

Fig. 7: Calculation results (meridional section): initial and optimized design

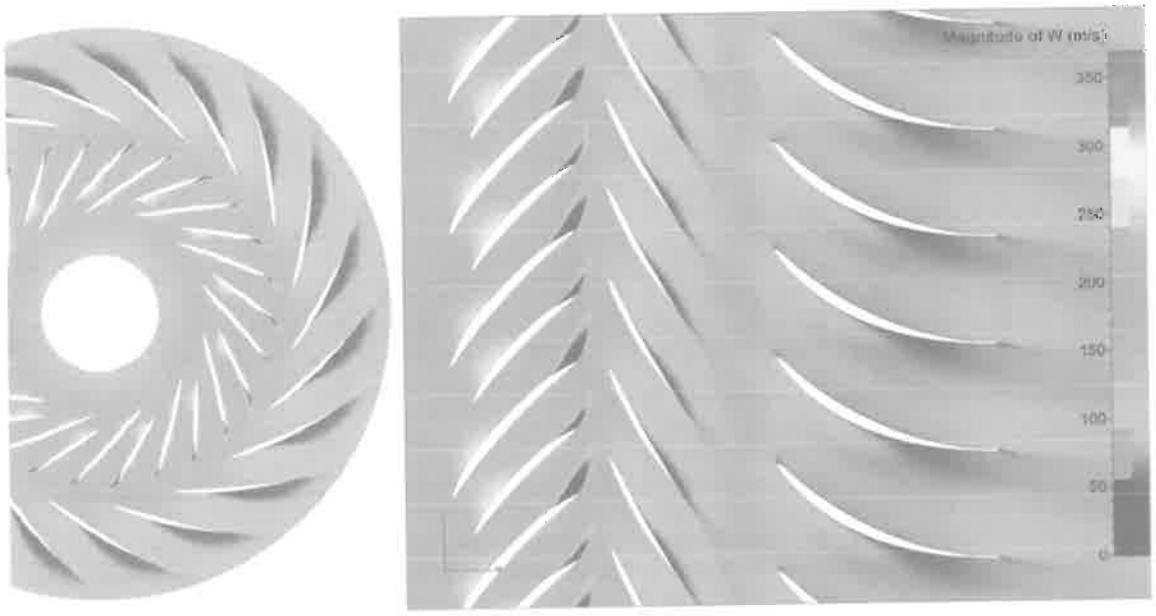

Fig. 8: Calculation results (conformal mapping)

Modernized compressor

The new gearbox couple and HPC were set identical to the former 1800 t/day modernization. High-efficient centrifugal stages with "compressor" type impellers with exit angles β_2 = 48° and 32° and vane diffusers are used in flow parts of the revamped compressor. In figure 9 and 10 the sketches of a cross-section of low pressure case (LPC) and high pressure case (HPC) of the 101J modernized compressor (1750 t/day) are shown.

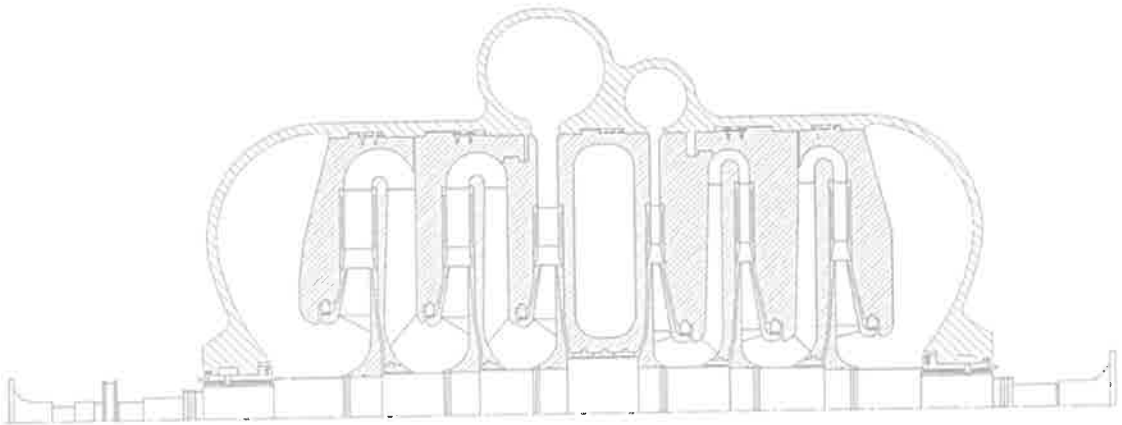

Fig. 9: Cross-section of low pressure case (LPC) of the modernized 101J compressor 101J (1950 t/day)

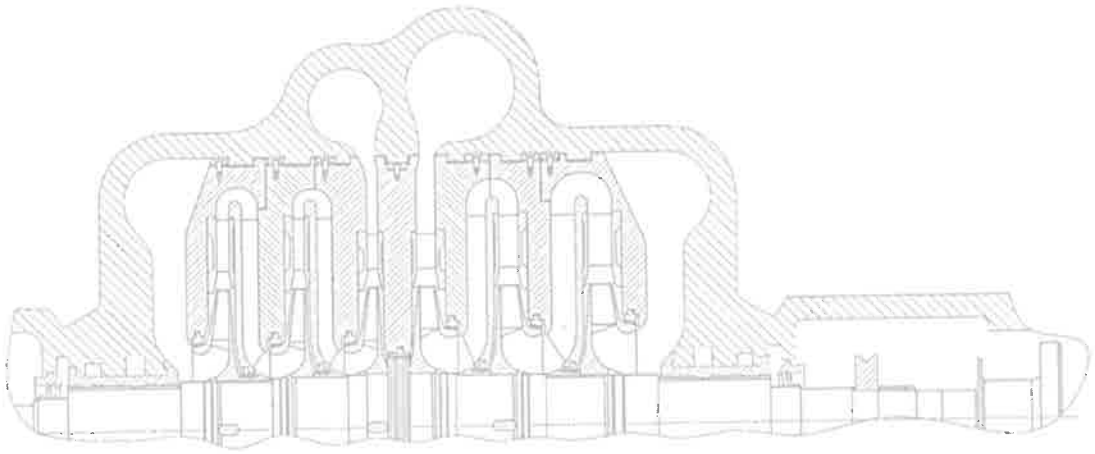

Fig. 10: Cross-section of high pressure case (HPC) of the modernized 101J compressor (1950 t/day)

In figure 11 and 13 the modernized LPC and HPC rotors for the 1950 t/day ammonia productivity are shown. The LPC 1st impeller is presented in figure 12. The optimized hyperbolic shroud profile design lets improve the stiffness of the construction also as the losses on the turn at the impeller suction. What about the dynamic stresses and mass of the impeller the radial cut off let us decrease it. The shifted splitter blade improves the flow at the suction making it more uniform, thus increasing the operational range of work (surge and choke) margins. This impeller is the result of more then 15 intermediate developmental works.

Fig. 11: LPC rotor of the modernized 101J air compressor (1950 of t/day)

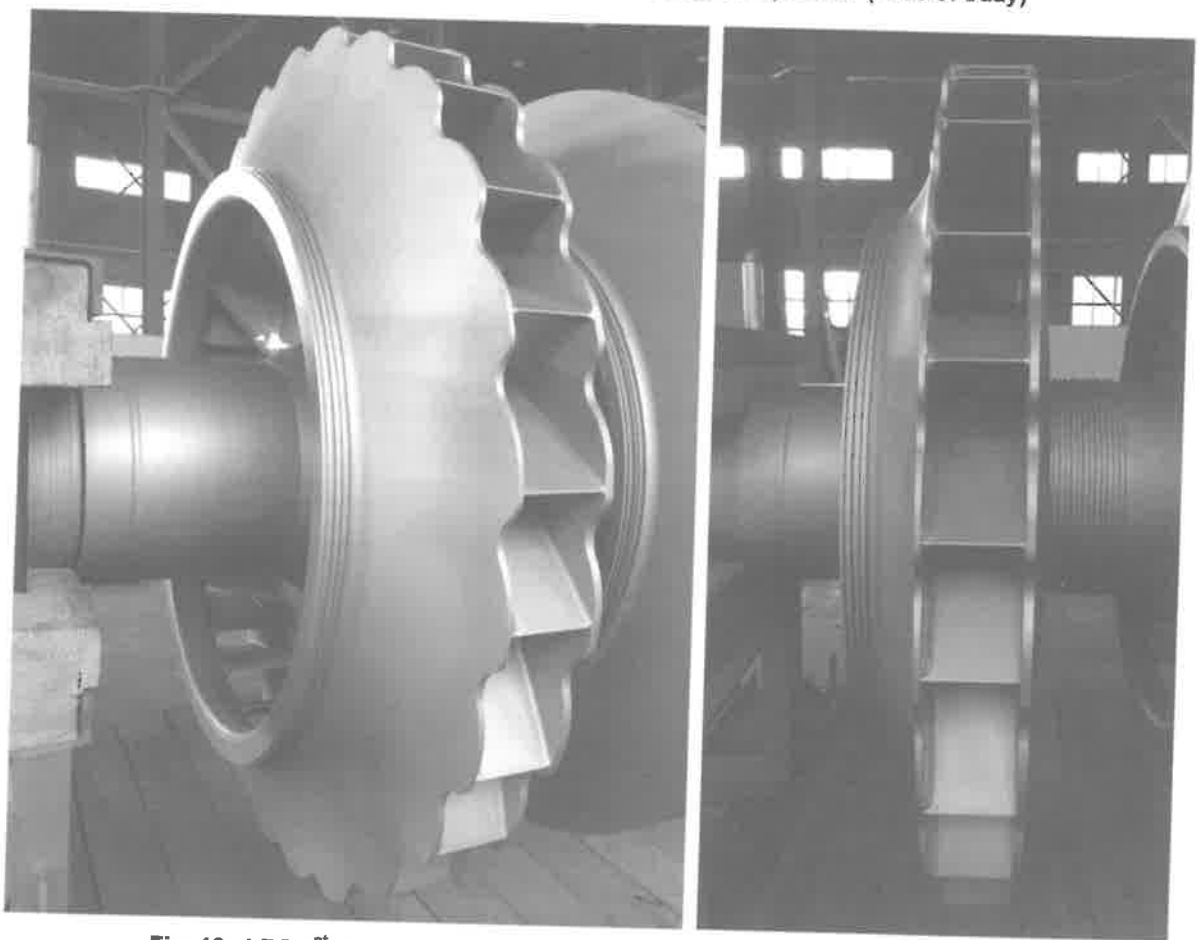

Fig. 12: LPC 1st stage of the modernized 101J air compressor (1950 of t/day)

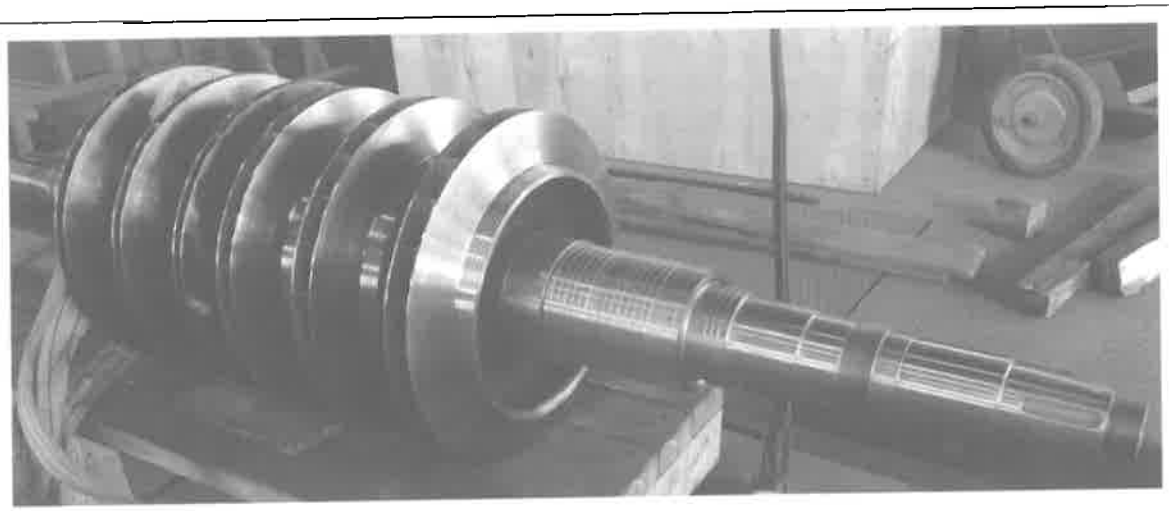

Fig. 13: HPC rotor of the modernized 101J air compressor (1950 of t/day)

The polytropic efficiencies of the original and modernized 101J air compressor sections are specified in Table 1.

Table 1
Polytropic efficiency of 101J air compressor sections

Section №	1	2	3	4
Compressed gas	Air			
Modernized compressor (1950 t/day)	0,83	0,82	0,83	0,82
Modernized compressor (1800 t/day)	0,83	0,81	0,83	0,82
Modernized compressor (1700 t/day)	0,83	0,81	0,77	0,74
Original compressor (1360 t/day)	0.8	0.79	0.76	0.725

Table 2 shows the parameters of the original centrifugal compressors for 1360 t/d and the modernized centrifugal compressors for 1750 and 1950 t/d production.

The power 11.3 MW of the 1700 t/d compressor with use of the original turbine is a breakthrough.

Table 2
General parameters of 101J compressor sections

Naming	Value	Original (1360 t/day)	Modernized (1700 t/day)	Modernized (1800 t/day)	Modernized (1950 t/day)
Suction pressure	MPa, abs.	0.97	0.97	0.97	0.95
Discharge s pressure		37.6	36.0	36.0	37.6
Capacity at STP (0°C, 0.1 MPa) at the discharge, Q_g, Nm³/h	m³/h	52000	60000	63000	72000
Shaft power	MW	**10.2**	**11.3**	**11.3**	**13.63**
Rotor speed (LPC)	rpm	5300	5200	5200	5200

The results of the air compressor modernization are notable: none of the tendered international company could offer such a great efficiency in old existing cases.

Entechmach have joint modernization project for both air compressor and steam turbine with **ALSTOM Power**. **Entechmach** designed and produced an exhaust of the modernized 101JT steam turbine and did the assembly of the **ALSTOM Power** turbine and **Entechmach** exhaust on its production facility. The picture of the exhaust is shown in figure 14.

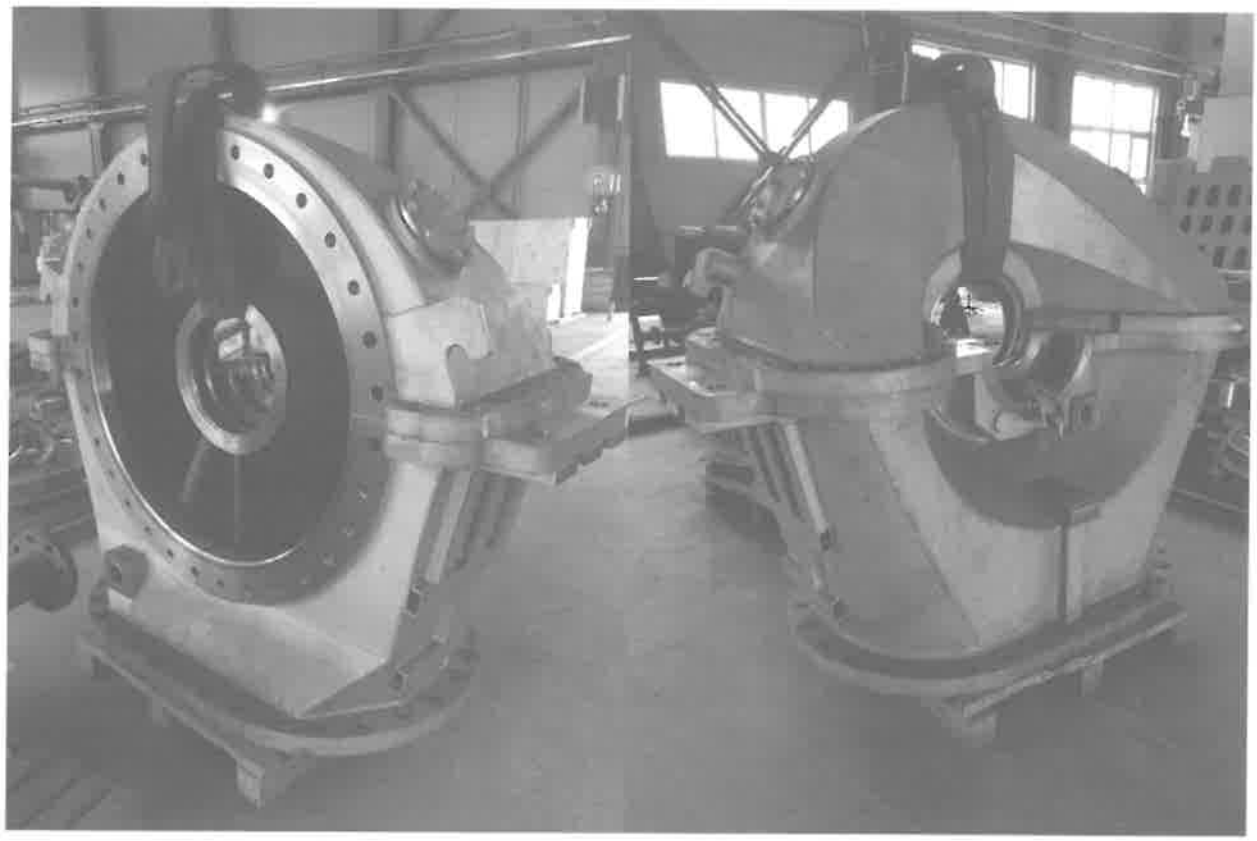

Fig. 14: Exhaust of the modernized 101JT steam turbine (1950 of t/day)

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