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Significant Reduction of the Ammonia Prime Cost and Operational Specific Energy Consumption of the Synthesis-gas Centrifugal Compressor

ANDREY SEMAKOV, VASILIY EVDOKIMOV, ANATOLIY REPINTCEV, ALEKSANDR LUBIMOV, MIKHAIL MOLODOV
“EnTechmach” RPC LLC
Saint-Petersburg, Russia

The problem of efficiency increasing of synthesis-gas centrifugal compressor in ammonia production with the current capacity of 1620 t/day is considered. The ways of increasing the flow parts efficiency of the modernized compressor are shown.

Nowadays a subject of centrifugal compressors modernization in the large-capacity fertilizers production units to reduce ammonia prime coast by means of operational specific energy consumption decrease is very important.

One of the most essential reasons of energy consumption increase is centrifugal compressors’ sections characteristics discrepancy, which results in significant decrease of compression process efficiency, unreasonable energy overconsumption and operational reliability degradation along with aerodynamic generating force. In connection with the above matter, there is a necessity of search and realization of new technical solutions.

MODERNIZATION OBJECTIVES
Ammonia production unit consists of synthesis-gas centrifugal compressor item 103J (or item 401), air compressor item 101J (or item 402), natural gas compressor item 102J (or item 403) and ammonia
refrigeration compressor item 105J. In this list, the synthesis-gas compressor is the most energy-consuming.

“Entechmach” RPC specialists worked out a synthesis-gas compressor modernization design for significant energy saving with the current ammonia capacity of 1620 tons per day. “Entechmach” RPC role in this matter is important because it is impossible to achieve high power saving without great experience in compressors modernization. Energy efficiency increase required detailed design of changes, which to be implemented in compressor flow part.

Modernization project in JSC Achema, Lithuania was based on the following main technical requirements:

- actual ammonia capacity of 1620 tons per day and synthesis-gas compressor discharge pressure (~230 kgf/cm² abs.) is saved;
- maximum unit energy efficiency (minimum specific energy) maintenance;
- maximum original elements usage (e.g., usage of original cases, pipelines, lubrication system, etc.);
- necessary power and rotation speed of turbine driver maintenance with minimum steam consumption.

**COMPRESSOR EFFICIENCY INCREASE METHODS**

“Entechmach” RPC provides ways of compressor modernization problem solution as follows:

- usage of new flow part, which is designed for new operation conditions (efficiency optimum corresponds the needed capacity);
- flow part perfection (polytrophic efficiency increase) compared to original one;
- intercoolers’ parameters improvement;
- compressor’s sections working modes coordination.

Compressor’s stages are designed oriented on experimental data bank owned by “Entechmach” RPC. It’s data obtained by testing centrifugal compressors flow channels on test stand. Besides the "similitude method" design, “Entechmach” RPC also use computation of three-dimensional models by finite element method.

As a result of modernization a compressor with improved technical-and-economic parameters and maximum usage of original elements is produced.

**ORIGINAL SYNTHESIS-GAS COMPRESSOR**

Synthesis-gas compressor item 103J type 463B5/5+272B5/5+272B7/R1 (Fig. 1) is the most complex and power-consuming in ammonia production processing chain. Original compressor consists of three cases, four sections with the recycle stage and three intercoolers. The intercoolers are air-type. LPC is placed on one side of a driver turbine, when MPC and HPC on another. What is more, speed of all rotors is equal to the turbine one. LPC consists of two uncooled sections (each has 5 stages), placed “back to back”. MPC has 10 stages without any intercooling; impellers placed “back to back" (5 stages from each side). Original HPC consists of 7 stages, compressing synthesis-gas, and 1 recycle stage, placed opposite to other impellers of HPC. Fig. 2 shows a principal scheme of original turbocompressor unit item 103J/JT. All stages were implemented with vaneless diffusers. Original compressor driver is the steam turbine with maximum power of 31.4 MW. It has one cylinder with two sections and one steam extraction.
Fig. 1: Synthesis-gas compressor item 103J

Fig. 2: Original turbocompressor unit item 103J/JT principle scheme

Fig. 3: Modernized turbocompressor unit item 103J/JT principle scheme

Original compressor has several imperfections:

- Compressor cases have a small radial length, hence “short” vaneless diffusers could not lower the velocity after impellers well, and therefore it reaches the value about 120-160 m/s. This results in decrease of polytropic efficiency because of losses increase in a meridional turn and return channel;
• impellers are placed too tight, stages limits extremely “squeezed” (Fig. 4). As the result there is an increased acceleration in impellers inlet. As well shaft labyrinth seals were designed with a small amount of «crests». That also results in decreased polytropic efficiency.

• impellers are made with parallel cover and main disks $b_2=b_1$: blades are milled in the covering disk body, what makes manufacturing process easier, but decreases efficiency. It is known that impeller width in outlet must be smaller than in inlet $b_2<b_1$ [1, 2].

• When increasing the capacity over 1700 tons of ammonia per day, usually unsteady phenomena in LPC and peaking vibrations appears, which limits the range of safe operation.

MODERNIZED SYNTHESIS-GAS COMPRESSOR

Modernized compressor must provide the same synthesis-gas capacity of $Q_{g(0^\circ C, 0.1 \text{ MPa})} \approx 186000 \text{ nm}^3/\text{h}$, recycle stage capacity – $Q_{g(0^\circ C, 0.1 \text{ MPa})} \approx 560000 \text{ nm}^3/\text{h}$ with maximum efficiency (according to the new technical specification).

During the modernization, following elements are produced:

• diaphragms;
• rotors;
• vane diffusers;
• labyrinth seals;
• damper bearings and plate couplings.

Modernized LPC, MPC and HPC significantly differ from the original ones. For example, meridional sections of original and modernized LPC are shown in Fig. 4 and 5, respectively.

1. Number of impellers is reduced by one in each compressor section (see Fig. 3);
2. Additional axial space in each section is used for each impeller inlet optimum flow arrangement and for increasing the «crests» amount in labyrinth seals;
3. LPC impellers diameters are reduced as compared to original. This results in rotary velocity \( u_2 \) decrease from 308 down to 285 m/s, what increases the efficiency and reliability;
4. Highly economical turbomachine “compressor” type stages with increased impellers width \( b_2/D_2 \) and sweepback cylindrical blades (exit angles from \( \beta_2=48 \) to \( 32^\circ \)) are implemented. Stages are optimized by finite element method, example is shown in Fig. 6. Polytropic efficiencies of original and modernized compressors are compared to each other in Table 1.
5. Impellers are machined with radial “chamomile” type cutouts in disks for increase of toughness and decrease of dynamic stress caused by unsteady communication of impellers and vane diffusers.
6. Impellers blade system is designed two-tired, short blade moved toward its average positon in the direction of rotation, what improves long blade flow-around, lowers the peak of inlet velocity [1]. This event also increases impellers reliability, because disks’ body zones between adjacent flow channels have different sizes and different excitation frequencies. If one passage is excited (oscillates), then another would damper its oscillatory energy.
7. “Shortened” vane diffusers with \( D_4/D_2=1,35-1,4 \), 5%-airfoil blades and near-optimal blade density (chord-spacing ratio) are used. It more effectively decrease velocity in same sizes down to 85 m/s instead of 120-160 m/s (as in the original compressor) (Fig. 6).
8. New return channels are designed to work in cooperation with new impellers and vane diffusers, taking into account data of the experimental research [4]. Modernized return channels perform gas supply to next stage inlet more effectively, almost except slowing down of the flow (i.e., don’t operate as diffusers).

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Fig. 6: Velocity calculation results (meridional section)

Diaphragms, suction and discharge chambers are framed in assemblages similarly to original ones with mounting on horizontal joint and bracing in axial direction. Modernized assemblage with vane diffusers is shown in Fig. 7. LPC, MPC and HPC modernized rotors are shown in Fig. 8, 9 and 10.
Fig. 7: Modernized LPC assemblage

Fig. 8: Modernized LPC rotor

Fig. 9: Modernized MPC rotor
Impellers are made of steel, which has necessary strength technological properties and is widely used in turbomachinery industry. Impellers are riveted design. Compressor shafts are connected by means of flexible coupling, require no lubrication. Labyrinth seal boxes of impellers and shaft are plain with horizontal joint and made of aluminum alloy. Diaphragms with return channel blades are made of steel with joint.

To increase compressor efficiency all flow channels are polished. Polished impeller and disk with blades are shown in Fig. 11 and 12. To decrease leakage grooves with fillers (sealing cords) were made on diaphragm joints (on assemblages outer diameters, on frontal walls of return channels and horizontal joints of diaphragms).

One of the reasons why there can appear self-induced oscillations (fluid-induced vibrations) in high pressure compressors is gas-dynamic excitations, caused in flow channel, in particular in labyrinth seals. In reference with the above, labyrinth seals of impellers disks were made longer in axial direction with the increased number of “crests”, bigger chambers between “crests”, what also reduce the leakage of gas by ~1.5 times. Gas enters the labyrinth seals twisted with rotary velocity bigger than velocity of shaft surface. Flow twist is especially intensive in labyrinth seals between compressor sections placed “back to back”. Flow twist also decreases the efficiency of seal. Therefore, special attention is paid to elimination of twist at inlet of intersectional seal. Holes break twisted gas flow, what prevents the appearance of exciting circulating forces. There is a V.B. Schnepf seal design used for intersectional seals, which include one row of holes made instead of “crest” row. There is an axial gap between the holes and the first “crest” (Fig. 14).
Original and modernized by “Entechmach” RPC compressor item 103J parameters comparison on nominal working mode is given in Table 2. Shaft power of modernized compressor is significantly less compared to original compressor.

### Table 1
Polytropic efficiencies of original and modernized compressors

<table>
<thead>
<tr>
<th>Section №</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>RS</th>
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<tbody>
<tr>
<td>Modernized compressor (1620 t/day)</td>
<td>0,83</td>
<td>0,79</td>
<td>0,78</td>
<td>0,76</td>
<td>0,82</td>
</tr>
<tr>
<td>Original compressor (design working mode) (1360 t/day)</td>
<td>0,77</td>
<td>0,74</td>
<td>0,7</td>
<td>0,73</td>
<td>0,75</td>
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### Table 2
Original and modernized compressors parameters

<table>
<thead>
<tr>
<th>Naming</th>
<th>Original compressor</th>
<th>Modernized compressor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor synthesis-gas capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qg(0°C, 0.1 MPa), nm³/h</td>
<td>151000</td>
<td>186750</td>
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<tr>
<td>Compressor recycle gas capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qg(0°C, 0.1 MPa), nm³/h</td>
<td>614000</td>
<td>563000</td>
</tr>
<tr>
<td>Synthesis-gas suction pressure, MPa abs.</td>
<td>2,60</td>
<td>2,39</td>
</tr>
<tr>
<td>Synthesis-gas discharge pressure, MPa abs.</td>
<td>33,87</td>
<td>22,54</td>
</tr>
<tr>
<td>Rotor speed, rpm</td>
<td>11194</td>
<td>10320</td>
</tr>
<tr>
<td>Shaft power, MW</td>
<td>28,5</td>
<td>~26,5</td>
</tr>
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</table>
One should notice that by the new project compressor’s modernization allow to lower the shaft power by ~4.5 MW. In the 2016 spring “Entechmach” RPC will mount and do the testing of the compressor in ammonia production site at JSC Achema, Lithuania. Received data will be analyzed and used to plot the characteristic graphs of compressor sections.

CONCLUSION

1. As the result of the modernization the new flow part of synthesis-gas compressor is created with usage of original cases. Such a compressor can be operated for several decades. In terms of efficiency it’s equal to a newly designed one in new cases.

2. The new flow part of modernized compressor provides nominal working mode with higher efficiency. Energy saving on nominal working mode achieves a value of 4.5 MW comparing to the original compressor. This result can be called outstanding, because today there are no such projects similar to “Entechmach” RPC compressor’s modernization.

3. Modernization project is designed so, that it can be performed for ammonia capacity range from 1550 up to 1950 tons per day. As a “basic” variant 1750 tons per day capacity was assumed. Hanging upon the “basic” variant, a flow part for compressor with lower or higher capacity is designed only by changing the vane diffusers and intersectional diaphragms. Rotors and other diaphragms still remain “basic”, and the efficiency remains approximately the same. For example, 1620 tons ammonia per day flow part is presented in this article and was designed by the method mentioned above.

4. “Entechmach” RPC has all necessary means for effective solving the turbomachine modernization problems in ammonia, urea, etc. production.

References


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