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DESIGN AND OPERATION PROBLEMS OF COMPRESSOR SYSTEMS[1]

by

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DESIGN AND OPERATION PROBLEMS OF COMPRESSOR

In this paper the critical areas of ammonia synthesis Turbo Compressors are identified and design philosophies discussed; design criteria of the associated auxiliary equipment are mentioned. The importance that machines be integrated with the plant system, so that their design limits cannot be exceeded is recommended; the availability of basic control and protection devices and of properly trained plant operators and maintenance personnel is considered.

INTRODUCTION

An attempt is made to contribute to the tecnnical pool of knowledge by critically looking at some outstanding design problems of compression equipment, centering the attention on the syngas compressor : in fact other compressor systems are less sophisticated and the list of their failures, as reported by yearly surveys of ammonia plant shutdowns, reads about the same.

The syngas machine is the most critical one not only for the hazard that could arise should the hydrogen-rich process gas leak from the compressor but due, also, to the high power, high speeds and high pressur involved. These require that best technology and quality controls and the most advanced prediction and design methods are used to achieve the highest availability and continuity of operation. Design extrapolations extended to a range beyond the limits that specific experience should impose have high potential risks of operating difficulties, in particular for the more severe process conditions, when the specified synthesis pressure is very high.

The most widely used industrial standards, that is to say API, NEMA, AGMA, ASME, ASTM, cannot cover the manufacturer's lack of know-how and experience.

PROGRESS IN THEORETICAL PREDICTION AND EXPERIMENTAL INVESTIGATIONS

The design problems of high speed - high pressure - low flow range centrifugal compressors are centered around the areas involving the careful analysis of the rotor system dynamics, the shaft-end oil seals, and the rotor axial thrust.

The dynamics of a rotating machine become progressively more complex as its design speed, power and operating gas density or pressure increase : higher dynamic forces excite the rotor bearing system to vibrate at its maximum sensitivity frequencies. The mechanical trouble-free operation of the machine is strictly correlated with the amplitudes and frequencies of rotor vibrations.

Lateral vibration phenomena are extremely complex:

Synchronous vibrations are caused by unbalance in the rotor system, misalignment and rotor or casing distortion.

Frequencies at multiples of the synchronous frequency of the rotor are attributable to internal rubs, passing frequencies and misalignment.

Asynchronous vibration frequencies that are not multiples of the synchronous frequency of the rotor and the sub-synchronous frequencies. are generated by internal hysteresis and friction forces, by aerodynamical and load-excited forces, possible rotating stalls at reduced flow, various pressure pulsations.

Each of the above factors affects the dynamic behaviour of the integrated system consisting of the rotor, the bearings (and oil seals) and the support structure; these forces can excite the system upto the loss of any margin of positive damping in the system, thus destabilising the rotor.

The design of the rotor system is optimized for dynamics by making use of elaborate computer programmes:

In the first stage, the system's lateral critical speeds are calculated in function of the equivalent support - bearing stiffnesses; This programme also gives the rotor mode shapes at the critical speeds for each selected value of the bearing stiffness.

In the second stage the rotor response to unbalancing forces is considered; the rotor motion through-out its operating speed range is studied as a damped system; the response plant gives the major semi-axis of the elliptical whirl orbit, at selected stations, for each speed.

The approach to valuate the stability limit is the calculation of the natural frequencies of the rotor - bearing - support system through the selected speed range; the programme gives the natural frequencies (synchronous and asynchronous) of the rotor system and the relevant damping factors all through out the speed range.

The proper use of computer programmes requires adequate knowledge of the response functions for selected type of bearings; The values of these spring and damping coefficients have been determined by various authors. In very high pressure enviroments all the forces should be carefully considered, including aerodynamical ones and those generated by turbulence and from any dissymmetry. The valuation of their magnitude and of their coefficients of influence becomes extremely difficult.

Computer's programmes are powerful forcasting instruments for the designer but the threshold of the instability needs sure confirmation by experimental testing of the prototypes under the same actual operating conditions. This is at present the only right way to know exactly the shaft's behaviour at very high pressures and to correct and improve the theory. The control of the stability is essential, being the instability, among all other vibrations, the most insidious and uncontrollable phenomenon that could happen. Whirl occurs suddenly and normally at frequencies lower than the running speed of the compressor.

Higher stiffness of the rotor and of the rotor supports are essential for safer margin of stability of the system or to achieve the stability upto a given speed.

DESIGN FOR RELIABILITY

The optimisation of an high pressure syngas centrifugal compressor demands careful attention to details of mechanics and thermodynamics. Due to the low flow range of capacities and the high head required, the impellers result of small diameter so as to achieve better polytropic efficiency by correct fluodynamic proportioning.

Clearances of the internal labyrinth seals must be set at a minimum to keep high the volumetric efficiency.

Diaphragms must be designed to withstand high differential pressures.

Rotational speeds and power result high. Thus internal and the external stresses, as can be applied through the couplings and piping loads, place more stringent requirements to the machinery designer.

The examination of the geometrical dimensions of the last make-up-gas compressor casing (that incorporates the recycle wheel) so as it is designed by Nuovo Pignone - for pressure upto 350 ATM - shows the careful study of its components.

The masses of the rotor are distributed so as to achieve the greatest stiffness together with the bearing's supports that are integral with the barrel end-covers. The outer surface of the shaft forms directly part of the fluodynamic path of the gas at impeller's inlet.

The impellers, that are manufactured by welding or spark erosion only, are shrink-fitted on the shaft in such a way as to avoid undesirable hysteresis affects.

With the radial bearings designed for high damping capability, above system exibits higher critical speed, low rotor sensitivity to unbalance, very high stability at any speed in the operating range upto and above 15000 RPM.

The oil seals bushings on the low pressure side of the shaft are to be made floating by fractionating the high differential pressure oil-to-atmosphere in several steps; then more than one oil ring is are used. Oil seals of particular designs can improve the stability. Expcial groving of the oil rings surfices facing the shaft, demonstrates positive damping contribution to the stability balance.

Positive and limited . instantaneous values of the differencial pressure oil-to-gas all around the shaft, needs careful design of the seal oil system; oil inhibitors and additives can produce lacquering and sticking of the seals by deposition of reaction products with ammonia traces in the gas stream. This phenomenon that is also favoured by high local temperatures is avoided by optimising the oil film flow.

The axial thrust in high pressure compressors requires extreme consideration other than the effects of the high differential pressures. Those coming from the pressure gradients between the facing surfices of the impellers and of the diaphragmsare greatly contributing to increase the total unbalanced thrust. Ofcourse the balanced load as obtained by opposing a big force to the above one - by the compensating device of the compressor - is limited to a small percentage only of the bearing's rating load. But due to the amount of the additional external forces that can be transmitted from the coupling and that are to be considered, the thrust is increased and may approach the rating load of the thrust bearing. Other axial forces, as applied by transients or by changed labyrinths clearances can further increase the thrust, upto values beyond any with-standing capability of the double acting thrust bearing.

Above critical conditions are unavoidable for the syngas compressors due also to limitations of the peripheral speed of the thrust collar that lubrication recommends not to exceed and that limits the size of the thrust bearing that can be selected.

Design of the internals so as to position the labyrinths all at the same diameter assures the best control of the internal axial forces, while the coupling thrusts can be controlled and kept down by good alignment and the selection of really anti-sludge coupings. For safety reasons other than reliability the bearing supports are integral with the end-covers. The provision of load measuring cells and temperature sensing devices is of utmost importance. High speed - high power transmission requires carefully designed couplings: hub and spacer are centered by the tooth's flame. The tooth profile is such to avoid corner loading (due to misalignments). The teeth surfices are continuously "washed" by the oil flow supplied through the holes between the teeth so that the oil or other impurities cannot stagnate.

Shrunk fitting of the hubs avaoids possibilities of unbalance and stress concentrations on the shaft's taper. The shaft-end strength results increased. Looseness due to teeth's sliding friction is eliminated. Couplings must be light to reduce negative influences on the rotor system stability. The bending radial force and moment due to misalignment are applied as near as possible to the bearings by the hub design.

OVERALL RELIABILITY

It is not possible to discuss all the other factors, but a fast mention of them is to be made.

The associated equipment, as the lube and seal oil system, the piping system with the gas exchangers around machines, the valves and the instrumentation should be considered integrated with the compressor train.

Reports of the operating experience show that auxiliaries are the main source of minor but frequent troubles. For this the possibility that all the system be engineered by a single supplier should be taken into consideration.

The machine can be damaged not only by upset conditions of the lube and seal oil system; operation in surge conditions, uncontrolled opening of the bypass valve, sudden variation of the load for accidental reasons or for erroneous operation, opening of an improperly designed relief valve, can generate tremendous dynamic loads.

Instrumentation and protective devices are of vital importance. It is fundamental to control the rotor shaft vibrations and axial thrust, The temperature of the oil to and from the bearings.

The differential pressure from downstream the balancing drum to the compressor suction and seal oil inlet to reference gas.

Two levels of alarm are to be provided for low lube oil pressure and for low level of Seal oil on the overhead tanks, for high vibrations, high axial thrust, high differential pressure through the diaphragm that separates the M.U.G. from the recycle section in the last compressor casing. The diaphragm is protected by the automatic balancing valve. The provision of the check valve that avoids possible reversal rotation, should isolation valves improperly operate, is important; the blow-out valve to depressurise the circuit in case of failure of the seal system is important for safety reasons too.

Beyond any consideration of design, experience shows that one plant is trouble-free operating, while another may have any sort of problems:

Safe and reliable operation of the plant requires that the operators be very well trained and highly responsible people. The same philosophy apply to maintenance personnel. They must become familiar with the equipment under control. They must understand the significance of vibrations and of an increasing oil temperature as of any other instument response or operation.

In the long term operation, changes of the tolerances can happen due to transients and normal wear.

Operation with gas under conditions different than normal, can promote corrosions or deposits on the rotor. Potential causes of troubles can be eliminated, if timely detected, by proper corrective action.

The comparative analysis of the instruments read-outs allows to diagnose the internal conditions of the machine and the control of unfavourable developing trends.

The maintenance of the protection devices and of the instrumentation does not need to be emphasised. By taking periodic measurements of the temperatures, the axial thrusts and vibrations of the bearings, and recording the trends, it's possible to plan the maintenance and prevent any emergency shut-down or serious failure.

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