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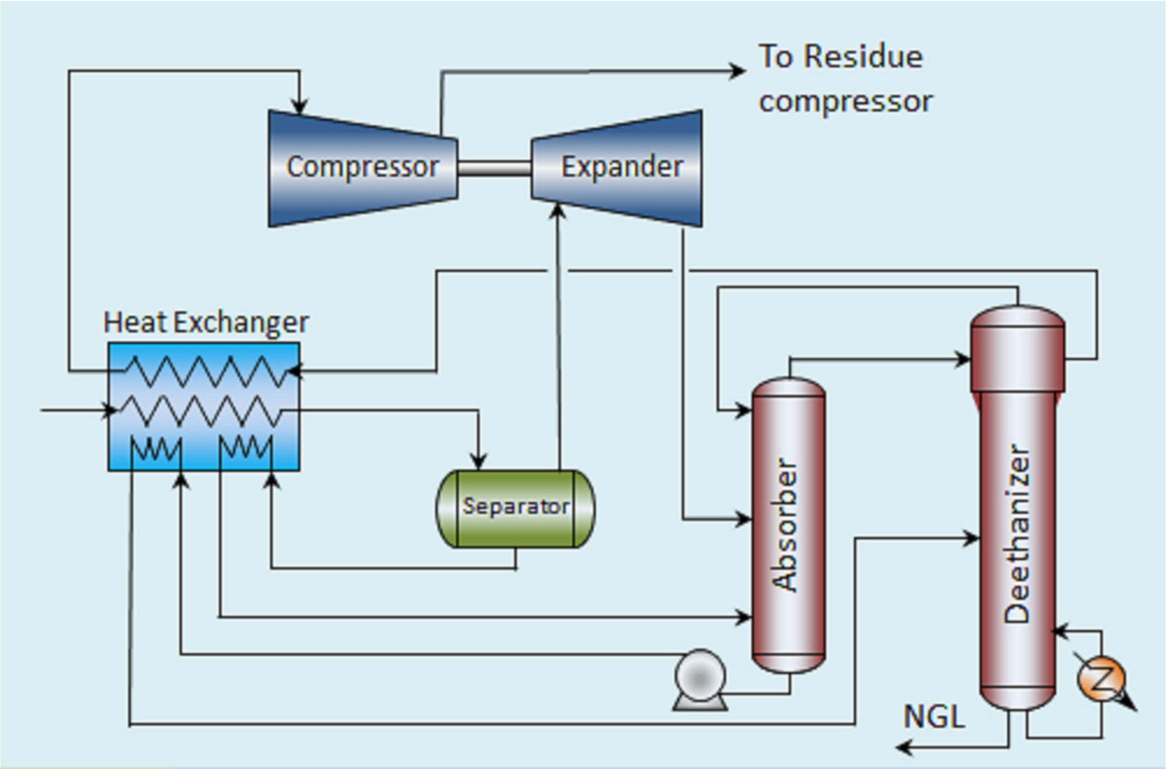
Control for Cryogenic Turboexpanders



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Enhanced Control Techniques for Cryogenic Turboexpander Recompressors.

Turboexpander compression trains are commonly used in petrochemical processes for extracting the heavier hydrocarbons from natural gas. These heavier hydrocarbon gases include but are not limited to ethane, propane, butane and pentane and are commonly called natural gas liquids or NGL. Figure 1 below shows a typical gas processing plant design. In this example, the expander is used to cool the process gas stream before entering a distillation column or deethanizer where it is used as reflux for the distillation. Gas from the top of the column is routed through a cold box before being compressed by the compressor portion of the turboexpander compression train.

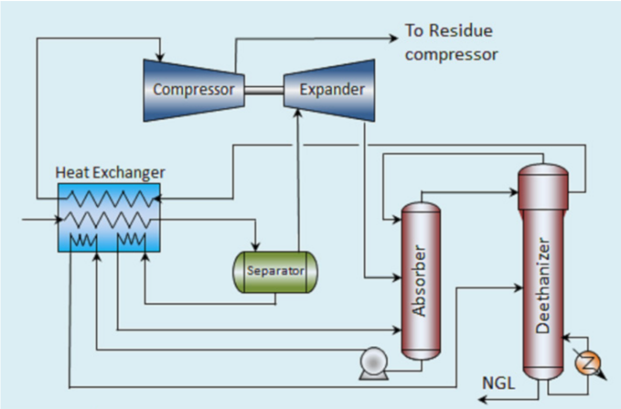

Figure 1 Typical Gas Processing Plant

The turboexpander and recompressor parts of the unit operate on the same shaft. A J-T (Joule-Thompson) valve is used to bypass flow around the turboexpander when the expander is offline or is unable to meet the flow demands of the process. The J-T valve is also used for startup of the train. The recompressor uses a recycle valve for antisurge protection as well as startup and shutdown of the unit. There is a bypass line around the recompressor to divert flow when the turboexpander train is offline and the process is operating in J-T mode. See Figure 2 below.

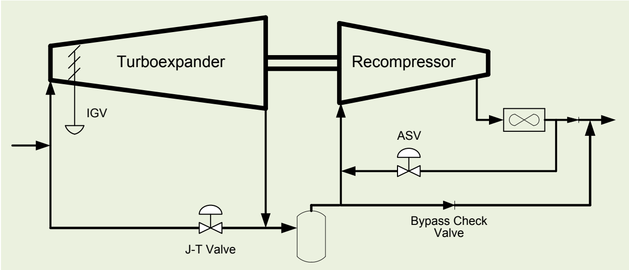

Figure 2 Typical Turboexpander Train

Production is controlled by manipulating the expander guide vanes. Typically this is done by maintaining a constant pressure at the distillation column, however, other parts of the process such as the inlet separator pressure or recompressor discharge pressure may be controlled as well.

Conventional Control Methods for Turboexpander Recompressors

Traditionally controls for the turboexpander trains are supplied by the OEM in a package together with the machine. There are several variations of these conventional control schemes used but most of these controls are based on simplistic assumptions and use simplified control solutions. In general, the conventional control schemes for turboexpander trains are based on a split range control between the expander guide vanes and the J-T valve with an addition of a low signal selector to allow for independent closure of the expander guide vanes. The control of speed is typically not performed continuously, but maximum speed is sometimes limited, and as a proxy for speed control sometimes the power dissipated in the expander is limited by controlling maximum acceptable pressure differential across the expander. While speed of the expander is limited by the guide vanes, the J-T valve is opened to meet process demands. The centrifugal compressor of the unit is equipped with a recycle valve for antisurge protection, although frequently the cooler enabling effective and prolonged operation of the antisurge protection is omitted. The control scheme for the antisurge protection of the compressor is often a simplified scheme sometimes even without the use of inlet flow measurement in which case antisurge protection is based on preventing high pressure differential across the compressor.

This control scheme for the Turboexpander-recompressor unit is simple in use but it presents a few problems. First, the scheme does not provide for a seamless operation of the expander when the speed needs to be limited. Between the moment the guide vanes begin to close to protect the expander and the moment the J-T valve begins to open to compensate for the flow that has to be rerouted, a gap exists due to split level solution in the output signal. The J-T valve does not begin to open until the signal of the pressure controller reaches the position corresponding to the beginning of opening of the J-T valve. In the meantime the controlled variable previously controlled by opening of the guide vanes shifts out of control and only later is being caught up by opening of the J-T valve. The system has a similar defect when going in the opposite direction from the J-T valve closing and eventually switching back to the guide vanes. As a result, every time the operation of the J-T valve is used or terminated, the control variable suffers an upset. The upset results in lower quality of operation of the NGL separation.

Second, the scheme does not assure smooth operation when the turboexpander-recompressor unit shuts down. In this situation the J-T valve must open rapidly to compensate for the missing flow. The split level control scheme does not allow for the J-T valve to rapidly travel to a position in which flow would be reasonably close to that of the expander prior to shut down. As a result, the plant suffers a large upset in pressure/temperature profile that definitely reduces quality and may lead to plant shut down. Third, the antisurge control of recompressor is often primitive and may not be able to protect the recompressor adequately especially when gas composition is changing.

Increasing Production of NGL

Although turboexpander trains require an overspeed protection system, most do not benefit as much from continuous speed control. Speed of the train is determined by the difference in torque developed by the turboexpander and the recompressor. The greater the torque delivered by the expander compared to that of the recompressor, the greater the rotating speed. Conventional control systems limit speed by limiting the opening of the expander guide vanes which limits the torque delivered by the expander. The torque delivered by the compressor remains relatively constant.

For most compressors, increasing the flow rate leads to increasing the power needed to drive the compressor. Since opening the recycle valve increases the flow rate through the compressor, the recycle valve can be used to vary the rotational speed of the turboexpander train. Therefore, the speed of the train can be first limited by opening the recompressor's recycle valve. This will result in an increase in torque delivered by the compressor while the torque from the expander remains the same and in turn will slow down the turboexpander train. By using the recompressor recycle valve first, the expander guide vanes are allowed to remain in a more open position and these results in an increase in condensate production.

The increased condensate is due to the expansion of gas in the expander in an isentropic work producing process whereas the expansion across the J-T valve is an isenthalpic process. This means that both temperature and pressure will be lower after expansion through the expander than it would be if expanded across a J-T valve. Lower temperature and pressure allows for increased production in condensates. Figure 3 shows the difference between the expansions of gas through the expander versus expansion across the J-T valve. The isentropic work producing expansion through the expander occurs from point 1 to point 2. The adiabatic expansion across the J-T valve that occurs at constant enthalpy is the nearly vertical path from point 1 to point 3.

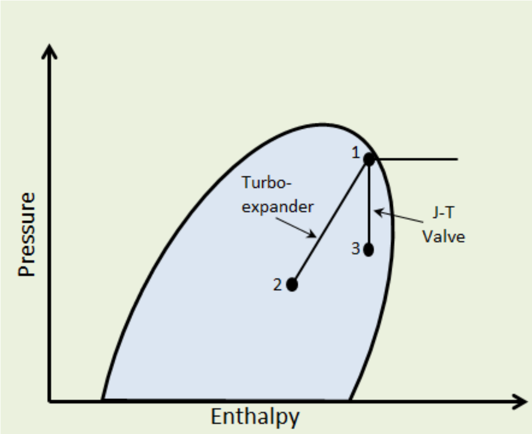

Figure 3 Turboexpander vs. J-T Valve Expansion

Separate control loops for guide vane and J-T valve

Split range control between the J-T valve and the expander guide vanes creates several challenges. First, the turboexpander guide vane actuation and J-T valve behave differently which requires making compromises in tuning in order to accommodate both. Second, provisions are necessary to allow for the J-T valve to take over control of the process when the guide vane control is being overridden due to either a limiting action or manual override.
Having separate control loops for the expander guide vane and the J-T valve as shown in Figure 4 allow for better control because each loop will have dedicated tuning which is more straight forward to implement than split range control. Often times the expander guide vanes are difficult to control and can lead to process swings or even expander trip on overspeed. Using a separate control loop for the J-T valve allows for it to assist the expander control during significant and rapid disturbances by opening the J-T valve for short periods of time to help stabilize the process.

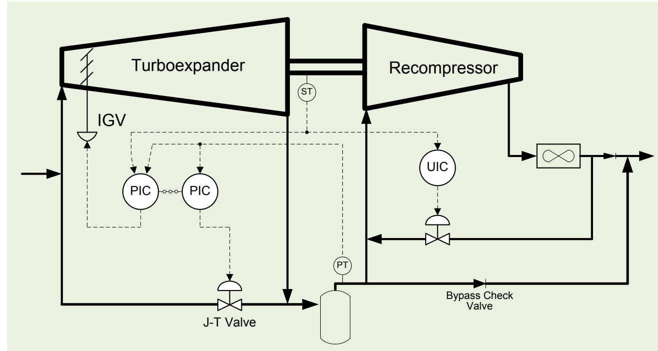

Figure 4 Turboexpander Train Enhanced Control Scheme

Pre-positioning the J-T valve upon a turboexpander train trip

Turboexpander trips can greatly affect the process resulting in loss of liquids production, gas being off speck, and downstream rotating equipment being driven towards surge. CCC's patented J-T valve prepositioning algorithm reduces the severity of the trip on the process. The J-T valve is prepositioned based on the capacity equivalent to the turboexpander's throughput immediately prior to trip. This strategy keeps the process online and minimizes temperature and pressure fluctuations in the distillation column, helps maintain inlet separator pressure, and keeps flow disturbances downstream to a minimum.

Critical speed avoidance using recompressor antisurge valve

The majority of turbomachinery has one or more critical speeds where the rotational speed excites a natural frequency of the machine. This includes turboexpander recompressor. For many units, especially of larger size, extended periods of operation at these critical speeds need to be avoided. When these critical speeds are below the normal operational range of the turboexpander train, the typical method of avoiding these critical speeds is to accelerate through these speeds at a higher rate. A speed range around critical speeds is often referred to as the "critical speed zone" and is defined by the equipment manufacturer.

In many cases, turboexpanders are sequenced up to the minimum normal operating speed rather quickly and do not require speed control through the critical speeds. However in some cases a controlled startup sequence is required and a speed controller is typically used to control the turboexpander guide vanes during the start sequence. Critical speed zones can be located just below the minimum operating speed and although not common, can also be located within the normal operating region of the turboexpander train. See Figure 5 below.

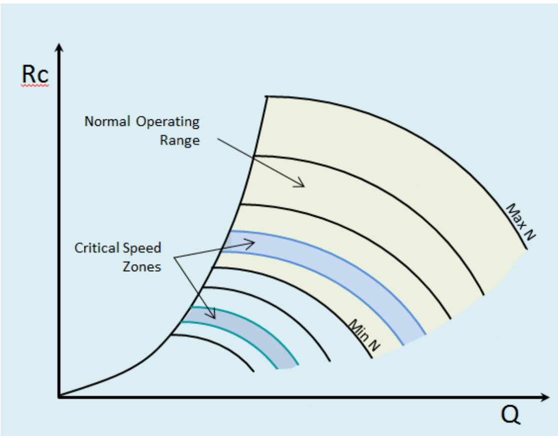

Figure 5 Turboexpander Critical Speed Zones

In some cases manipulation of guide vanes can be unpredictable making them difficult to control. CCC's patented compressor-expander set critical speed avoidance algorithm offers an alternative method of critical speed avoidance. Prior to starting the turboexpander train, the guide vanes are in the closed position as is the trip valve. The recompressor's recycle valve is full open in the meantime. The turboexpander train is typically started by opening the trip valve or block valve causing free rotation of the train. The IGVs are then ramped open to further accelerate the train. The antisurge controller is sequenced to ramp the recycle valve closed at a specified minimum rate. When the turboexpander train reaches a critical speed zone, acceleration of the train is increased by increasing the closing ramp rate of the recycle valve. Once through the critical speed zone, the antisurge controller returns to the normal start ramp rate. See Figure 6 below.

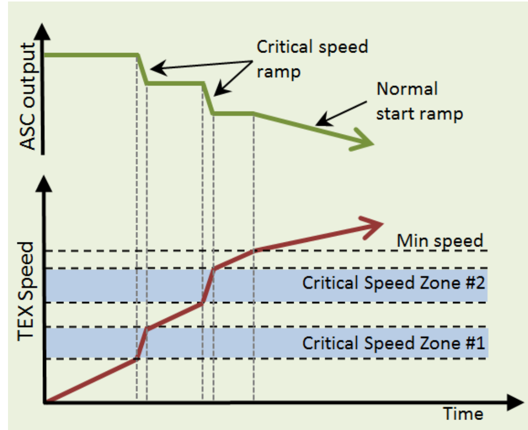

Figure 6 Startup Critical Speed Avoidance

When critical speed zones are located near or within the normal operating speed range of the turboexpander train, process disturbances can cause the train's speed to decrease into the critical speed zone. The recycle valve can be used to quickly drive the train's speed down through the critical speed zone. Once the antisurge controller has completed the startup sequence and has cleared the critical speed zones, it begins normal antisurge control and monitors the train's speed. If the speed decreases into the critical speed zone, the antisurge controller opens the recycle valve to increase the flow rate through the compressor in order to decrease the turboexpander train's speed. See Figure 7 below.

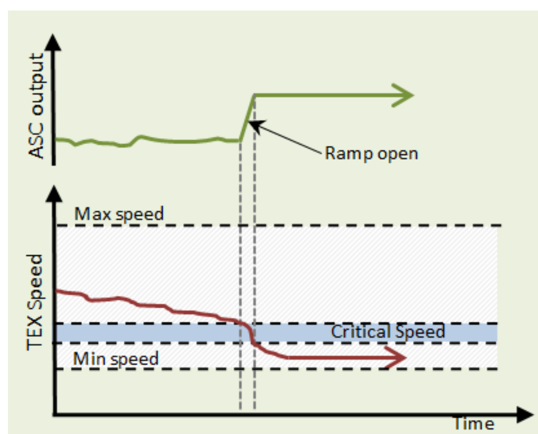

Figure 7 Critical Speed Avoidance by Opening ASV

Once speed has been decreased through the critical zone, the speed of the turboexpander train is maintained just below the critical speed zone until process conditions allow for the speed to be increased back through the critical zone and normal operation can resume.

The capacity of gas processing plants have increased in the past several decades requiring many plants to operate two or more turboexpander trains in parallel. The enhanced control schemes discussed in this article apply to turboexpander trains operating in parallel however there are additional control challenges that are introduced when they operate in parallel. These additional challenges include load sharing between units, prolonged operation of one of the units with substantial recycling, startup and shutdown of parallel units and coordinated control with one or more J-T valves. Due to the complexities of controlling parallel turboexpander trains, a separate article is necessary to fully cover this topic.

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