EFFICIENCY DRIVEN HOME

JIM BERRY, USA, EXAMINES OVERRUNNING CLUTCHES FOR DUAL-DRIVEN COMPRESSION EQUIPMENT.

Increased energy costs, coupled with stricter environmental regulations, mean that waste energy recovery equipment and systems don't just make economic sense, they may be essential to obtain permission. In addition, large hourly, daily or seasonal price swings provide a strong incentive to design systems with energy source flexibility, allowing real-time optimisation of energy costs.

Since waste heat energy is often variable or interruptible, the equipment design must accommodate variability. A common solution is to have the primary driver hard-coupled to the driven machine, and using an overrunning clutch to connect the energy recovery driver (steam turbine, hot gas expander, etc.) to the driven machine. Systems that use multiple energy source systems are also well suited for the application of an overrunning clutch.

A dual-driven train with an overrunning clutch enables one driver to be disconnected from the train and stopped while the second driver continues to power the driven machine. It also allows the driven equipment to begin operation when the second driver is not initially available due to process or other constraints.

Overrunning clutches or 'free-wheels' are used in hundreds of different dual-drive applications in marine, power generation, refinery, petrochemical, and oil and gas applications. Below is a description of how they operate, followed by examples of how these clutches are used to address the unique compression needs of a variety of industries.

General description and configurations

A freewheel or overrunning clutch is a one-way clutch that allows the transmission of torque in one direction from

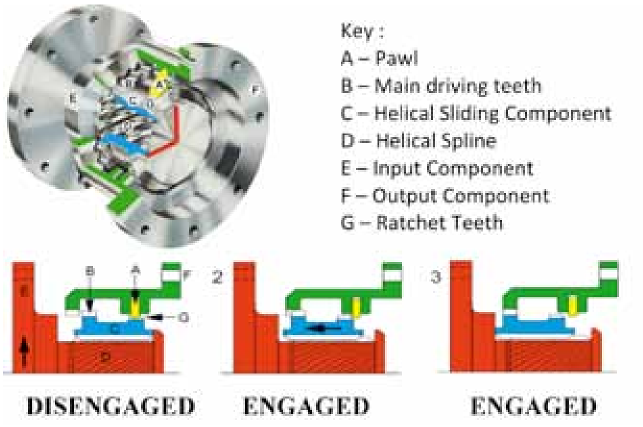

Figure 1. Please insert caption.

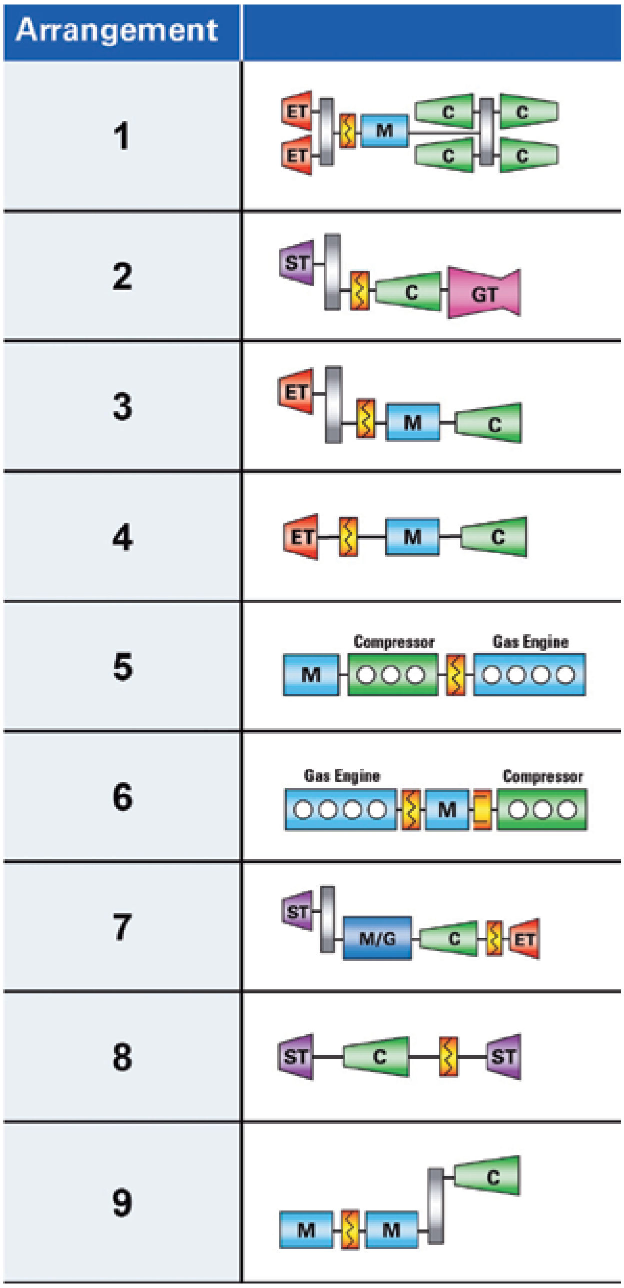

Figure 2. Please insert caption.

one rotating shaft to another. The clutch mechanically engages when the driving shaft speed attempts to overtake the speed of the driven shaft and disengages when the torque reverses on the driving shaft or the driving shaft speed decreases below that of the driven shaft. The condition of 'freewheeling' occurs in most bicycles when the rider stops pedalling and the bicycle coasts. Without a free wheel, the rear wheel would drive the pedals around. Overrunning clutches are not friction clutches and cannot force the speed of one shaft system to match the other.

Low power overrunning clutches

Low power overrunning clutches up to a few hundred horsepower rating include ramp-and-roller and sprag-type clutches. Both of these synchronise and transmit torque by wedging loose parts between inner and outer cylinders within the clutch. They are generally applied in low power services below 3600 rpm. The clutch components can deform – particularly under high stress and if there is some accompanying machinery vibration. They are also sensitive to shocks, sudden torque overloads and cleanliness of lubricating oil. That said, they are still well suited for many low-power service applications.

High power overrunning clutches (gear tooth type)

For high-horsepower, critical service applications, an automatic overrunning clutch which transmits torque through multiple gear teeth and separates the synchronising function from the torque carrying components, such as a synchro-self-shifting (SSS) overrunning clutch, is normally utilised.

With such clutches, small pawls are used to mate with ratchet teeth to align and then shift the clutch teeth into engagement along helical splines (Figure 1). The teeth are engaged automatically at synchronism at any speed from rest to full operating speed. The pawls and ratchets are inactive except during the short engagement process. Once engaged, torque is transmitted through the surface contact of concentric involute shaped teeth. An internal oil dashpot, between the input and output components, cushions the engagement of the clutch.

High power overrunning clutches can be supplied supported by the shafting and engineered to either act as a solid coupling when engaged and transmitting torque or to accept axial and offset misalignment. Alternatively, overrunning clutches can be mounted in an oil-tight housing that can be foot-mounted or connected to the casing of the driving or driven machine.

Reasons for dual driving a compressor train

There are a number of reasons for dual driving a compressor train and installing an overrunning clutch. Following are specific proven application examples each referenced back to Figure 2, showing schematics of the train arrangements. A few potential examples not yet implemented are also discussed.

Using a clutch to engage a driver not initially available

PTA process (Figure 2, arrangement 1)

In the purified terephthalic acid (PTA) process, air is compressed to about 200 psia and fed to a reactor where the oxygen in the air is used in the process. Spent air – at about 150 °C and still at approximately 200 psia – is expanded back to atmospheric pressure in a radial inflow power turbine used to help drive the compressor train. It takes a few hours to start and stabilise the process, therefore, the train is initially started with an electric motor with engagement of the power turbine using an SSS clutch occurring once the process is stabilised and pressurised hot spent air is available.

Typically these power turbines are in the 10 - 25 MW size range. In certain cases, additional heat is added to the spent air and the power turbine generates up to 45 MW, with the excess power used to run the motor as a generator, feeding the power to the grid. Two recent BP Amoco installations had expanders rated at 29.5 MW at 1000 rpm and 42 MW at 1000 rpm at Capco, Taiwan, and Zhuhai, China respectively.

Combined cycle compressor trains (Figure 2, arrangement 2)

Another example of this type of application is a combined cycle compressor train in which the compressor is driven by both a gas turbine and a steam turbine. The clutch, installed between the steam turbine and compressor, allows the gas turbine to start up separately from the steam turbine. Once steam generated with the gas turbine exhaust is available, the steam turbine is started and engaged. DCP Midstream uses two dual driven compressor trains at its Okarche, Oklahoma, gas processing plant. Clutches connect 1865 kW, 5560 rpm geared steam turbines to 2945 kW, 14 525 rpm gas turbine driven compressors.

Thermal oxidiser with compressor and hot gas expander (Figure 2, arrangement 3)

Thermal oxidisers, used to oxidise dilute streams of hazardous compounds, often use a compressor to supply air to a catalytic oxidiser, the exhaust energy of which is used to drive an expander. Again, similar to the PTA process, the clutch allows a less complicated start-up procedure and eliminates having to install a motor large enough to start up both the compressor and expander.

Using a clutch to engage an emergency driver

Emergency expander turbine for controlled process shutdown (Figure 2, arrangement 4)

Licensed by Univation Technologies, the Unipol polyethylene process cycles gas through a fluidised bed reactor. In the reactor bed, polyethylene dust is produced that is periodically purged from the reactor. A centrifugal gas compressor (typically about 6 MW) drives the feed gas through the reactor vessel, a cooler, and back to the compressor suction. The plants are not typically located near a steam source and therefore the compressors are usually driven directly by two pole motors. If the power should fail and stop the gas circulation, the reaction would continue for some time plugging the reactor vessel with plastic, resulting in a multiple day plant shutdown.

To allow time for a controlled shutdown in the event of a power failure, an emergency turbine driven by vented reactor gas is connected via a clutch to the free end of the motor shaft. The expander starts up almost instantly and the clutch engages the expander to the motor shaft as the train is coasting down, engaging at about two thirds speed, and continues to run for about 10 mins as a 'kill gas' is injected into the system to stop the process. The relative acceleration of the two shafts (the coasting down motor and compressor and the accelerating expander) is about 1000 rpm/sec, relying on the built-in dashpot to cushion the engagement. There are over 70 SSS clutches installed in this application worldwide.

A potential application of an over running clutch and an emergency turbine could be in refinery processes where a motor driven compressor is used to cycle gas through a fired heater, such as a catalytic reformer. A power failure can cause tubes to bow as gas flow stops and residual heat cannot be carried away. The emergency turbine could be a steam turbine with simple atmospheric exhaust.

Using a clutch to allow use of alternate power sources

Dual-driven pipeline compressors (Figure 2, arrangement 5)

Driving a pipeline compressor with both a gas-fuelled prime mover and an electric motor, and including a clutch in the train to allow shifting from one driver to the other, has several advantages. Reliability is improved by allowing the motor to drive the compressor while repairs are made to the gas engine, or utilising the engine in the event of an electrical power failure. The clutch allows choice of energy supply depending on real-time prices. At times when the compression duty requires less power than is available from the gas-fuelled driver, this excess driver power can be used to generate electric power for sale to the grid.

Energy Transfer Partners, LLP, Dallas, Texas has installed 42 compressor trains consisting of 1.5 MW at 1200 rpm gas engines, SSS clutches, reciprocating gas compressors, and electric motors. The company is now engineering a larger 2.5 MW gas engine and 5 MW gas turbine dual-driven pipeline compressors for future applications. This dual drive arrangement also allows the use of electric motors as the primary driver in locations where the local grid can not support the motor inrush current by using the gas engine to bring the train up to speed before energising the motor.

The most recent energy transfer use of this concept is for a gas storage application in which a manual disconnect coupling (in addition to the clutch) is provided to allow the engine to drive only the generator, allowing the owner to sell power to the grid during the months of the year when compression is not required (Figure 2, arrangement 6).

Using a clutch to allow shutdown and maintenance of one driver while keeping the train running

Using a clutch in an FCC power recovery turbine to improve

availability (Figure 2, arrangement 7)

Often in a complex machinery train of multiple drivers and driven equipment, the maintenance intervals vary widely between the various pieces of equipment. A good example is the fluidised catalytic cracking (FCC) air compressor train. These trains typically consist of an axial compressor, steam turbine, gear, motor/generator and power recovery turbine (PRT). The maintenance interval for the gear and generator usually well exceeds five years. The compressor and steam turbine fall in the three to five year maintenance interval range. However, the PRT, depending on the corrosiveness and amount of particulates in the expanded gas stream, sometimes requires a shutdown in less than three years. Or, due to a process upset, the PRT can have an unscheduled shutdown at any time, costing hundreds of thousands of dollars per day.

By installing a clutch between the output shaft of the PRT and the axial compressor, and sizing the motor/generator and/or steam turbine to be able to pick up the load of the PRT, the PRT can be taken offline and repaired while the remainder of the train and the FCC unit continues to operate. After repairs are made, the PRT can be started and re-engaged with the running train. The clutch also allows for easier, less complicated starting of the complete train and process.

Using a clutch to meet changing or rarely occurring process needs

Accommodating changes in steam availability (Figure 2, arrangement 8)

When the 2-body process air compressor train was installed at the Invista acrylonitrile plant in Victoria, Texas almost 40 years ago, the train was driven by a backpressure steam turbine. At the time it appeared there would always be a good match between the steam flow needed by the back pressure turbine and the process steam demands. However, a few years after start-up, the process steam requirements became seasonably variable and at times less than what the backpressure turbine needed to drive the compressor. Exhaust steam from the turbine had to be vented to atmosphere, in order to provide enough flow to produce the required power. To solve this problem, a condensing steam turbine was added to the train using a clutch to allow engagement of this turbine to the already running train when necessary. With the addition of the condensing turbine, whenever the process could not absorb the steam flow required by the BP turbine, the excess flow was directed to the condensing turbine inlet producing the additional power required by the compressors and reducing the total steam demand.

Motor driven hydrogen recycle compressors in reformer applications during catalyst change out (Figure 2, arrangement 9)

Most hydrogen recycle compressors installed today are driven by constant speed electric motors through a speed increasing gear box. These are high head centrifugal compressors. The normal process flow and head requirements can be met at a constant compressor speed. However, once every few years, the process loop needs to be opened to change out the catalyst. Before the process can be re-started, the loop must be purged of air. This is accomplished by cycling nitrogen through the loop, adding and bleeding nitrogen from the loop as it is being recycled, until no oxygen is present.

The high head compressor produces a low ratio (about 1.5-to-1) when operating on the normal hydrogen rich gas with a molecular weight of around 3-to-5. Thermodynamically, a low ratio means a low temperature rise. When cycling nitrogen through the loop, the same compressor head results in a ratio of more than 4 and a discharge temperature beyond the design limits of the compressor. Further, the high ratio causes a much greater volume reduction, as the nitrogen travels through the compressor compared to operation on the low molecular weight gas. This large volume reduction causes the last few impellers to operate in a dangerous surge condition.

The solution is to reduce the head by operating the compressor at a reduced speed during this nitrogen purge operation. The challenge is to provide this rarely required second operating speed at a reasonable cost. A low cost solution is to use a second lower speed motor and a clutch connecting this lower speed motor to the free end of the higher speed motor. During the nitrogen cycling operation, the breaker would be opened on the normal speed motor and the low speed motor would be used to drive the train. Because of the lower head and lower loop operating pressure during the nitrogen operation, the low speed motor need only be 15 - 20% of the power rating of the high speed motor.

Smooth sailing

A key issue with all rotating equipment used in critical service applications is reliability. Of the above nine compressor solutions, seven are already in application, some of them for decades. The user with the largest number of installed and operating SSS clutches used in critical service is the US Navy with over 900 in operation. Some of these clutches have been operating for over 30 years.