Speed Regulated Air Compressors

1.0 Introduction

Surveys show the average 60-100 hp air compressor operates for approximately 4000 hours per year providing an average 70% of maximum output capacity. More than a quarter of those surveyed only utilized 50% or less with higher capacity only being required during short peak demand periods. Below full output capacity is where the true energy saving potential of the SR compressor is realized. Unlike a conventional air compressor, the SR compressor varies the speed of the compression element, using a unique high efficiency variable speed drive, matching energy consumption to air demand without the need to off load or restrict air intake. This gives the SR compressor a significant advantage compared to other conventional air compressors which suffer ever increasing losses as average air demand reduces.

2.0 Conventional Air Compressors

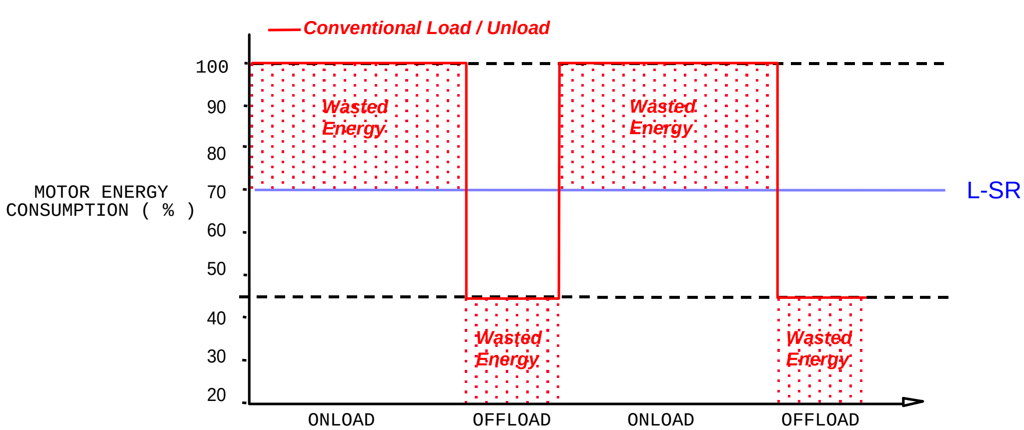
Why conventional air compressors suffer disproportionate efficiency losses when operating below full output capacity :-

A conventional air compressor generally regulates output in one or two ways; On load / Off load or Air Inlet Valve Modulation

2.1 On load/Off load

In this mode of regulation the compressor will deliver maximum air output when on load and zero output when off load. The compressor will load when air system pressure falls below a pre-set pressure level, and off load when pressure reaches a pre-set upper pressure level. Air system pressure will rise and fall as a function of the amount of air used compared to the amount of air being generated by the air compressor when on load. The lower pressure level is generally set near to the minimum required air system operating pressure with the higher pressure level usually set 7 psi (0.5 bar)) above this setting.

Motor energy consumption comparison



When loaded the compressor will consume maximum power and operate at maximum efficiency. When off load, the drive motor will continue to consume 40-50% of full load power as motor efficiency falls from approximately 0.925 to 0.9 and the power factor falls from approximately 0.9 to 0.6 or less, depending on the type motor. When air demand is below the maximum output capacity of the air compressor, the compressor will spend a period of time in the off load state proportional to the percentage air demand to compressor maximum output capacity. The lower the air demand, the longer the compressor will run in an off load state.

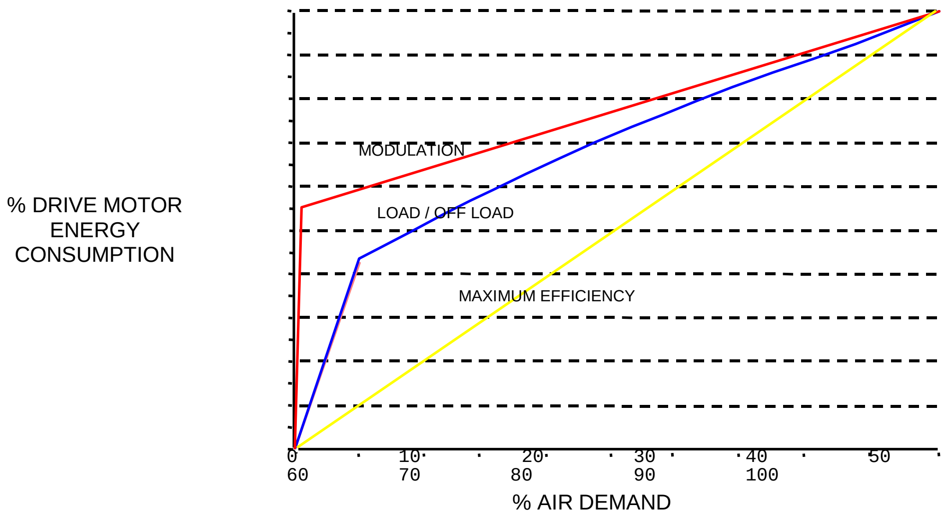
When a conventional compressor operates at 70% of maximum output capacity, the compressor will spend 30% of the time running in an off load condition consuming approximately half full load power. While on load the compressor will consume maximum power resulting in unnecessary energy waste in both load and off load conditions. The SR compressor overcomes this situation by reducing the compression element speed to 70% load consequently reducing drive motor energy consumption in proportion. In this manner the SR compressor is able to reduce running energy costs by up to a quarter at 70% load, compared to a conventional compressor of the same rating.

2.2 Modulation

In this mode of regulation an air intake valve is used to progressively restrict compression element air intake in proportion to air demand. This gives the advantage of maintaining a near constant delivery pressure with the air intake valve modulating in response to changes in air system pressure. In this condition the compressor remains constantly in a loaded condition, regardless of air demand, with the drive motor consuming a disproportionate level of energy as air demand reduces. The energy consumed by the motor will reduce as the air intake is restricted, but will always be much higher than running the compressor in an off load state, even when the air intake is completely closed and no air output is being produced. Continuous mode is advantageous when air demand is continuously near maximum output capacity of the compressor, giving the ability to operate at a near constant pressure, but becomes progressively less efficient than other modes of regulation as average air demand begins to fall.

Only at near full output capacity is a conventional compressor able to return value for money and offer efficient conversion of electrical energy in to compressed air. When operating below approximately 85% of full output capacity, efficiency losses begin to become significant and energy costs become disproportionately high compared to the amount of compressed air produced.

Energy consumption of air demand comparison



3.0 Variable speed regulation

A variable speed regulated air compressor attempts to maintain a maximum efficiency relationship between air demand and energy consumption keeping energy costs in proportion to the actual amount of air used. How efficiently a variable speed drive system is able to achieve this goal depends on the drive technology employed.

3.1 Frequency Inverter Variable Speed Drives (VSD)

A standard fixed speed ac induction motor, as used on all conventional electrically driven air compressors, can be made to change speed by using a frequency inverter drive to vary the frequency of the power supply to the motor. Such drive systems are called Variable Speed Drives (VSD) and their use in air compressor equipment has shown good energy saving results. There are, however, several drawbacks using a frequency inverter drive.

1) Drive Efficiency
A frequency inverter operates by converting main power supply alternating current (ac) into direct current (DC). This is then converted back to ac again but at a controlled frequency. The frequency of the power supply to an induction motor determines rotational speed. When energy is converted from one form to another, losses occur. A frequency inverter performs two energy conversions and hence suffers two conversion loses reducing the overall efficiency of the drive system.

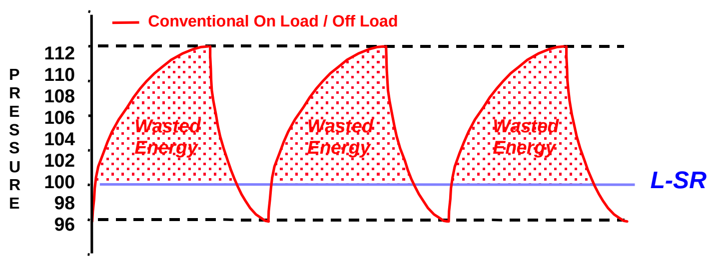
2) Complexity and Reliability
A frequency inverter drive is a high cost, high component count, complex system. Reliability of electrical systems can, to an extent, be forecast as an exponential of the number of components liable to failure.

3) Inherent Motor Inefficiency
Standard ac Induction motors are designed to operate at one particular fixed speed. When a frequency inverter is used to vary the speed, the efficiency of the motor reduces, generally resulting in increased heat and noise. The greater the difference in speed from the original design speed, the greater the efficiency losses, and these losses become significant at speed extremes. This disadvantage can be overcome to some extent by utilizing a specially built, service factored, motor designed for variable speed operation, efficiency losses at varying speeds, however, still occur. In addition, inductive power factor effects, associated with all induction type motors, continue to reduce efficiency further as motor loading varies.

3.2 Constant pressure regulation

Variable speed drive regulation systems operate on a principle which gives near constant air delivery pressure. System air demand is detected by fluctuations in air system pressure. When demand is high air system pressure will naturally begin to fall. The variable speed regulation system detects this and increases compression element speed to compensate. When demand falls, air system pressure will begin to rise, and speed is then reduced to compensate. The SR compressor uses a highly accurate electronic pressure sensor to monitor air system pressure, and can respond to pressure fluctuations of less than 7 psi (0.05 bar).

Pressure regulation comparison picture



example: required air system pressure 100 psi g minimum

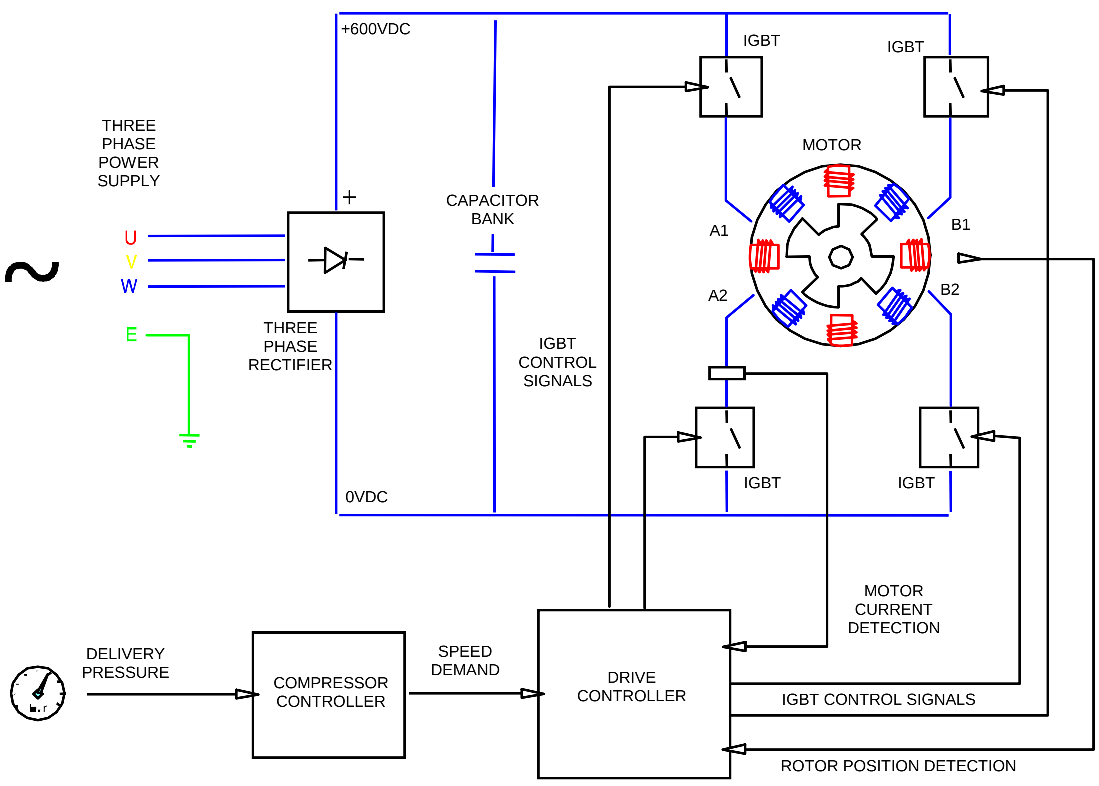
Maintaining a steady and constant air system pressure can give added benefits to the end user's site process, resulting in cost saving opportunities in product quality and process stability. Avoiding the conventional necessity to repeatedly pressurize the air system to a higher than required pressure, then allowing the pressure to fall towards the minimum required pressure again in a cycling repetitive sequence, gives an instant opportunity for direct energy cost savings. With delivery air output continually matched to demand, at a steady and constant pressure level, the SR compressor can operate at a pressure much closer to the required site minimum pressure level, saving the energy costs accumulated in pressuring the air system to higher pressure levels.

3.3 CompAir Switched Reluctance, Speed Regulated Drive (SR)

The CompAir L-SR has been designed from the ground up as a speed regulated air compressor with maximized efficiency and reliability as design foundations. The unique SR drive system at the heart of the SR compressor. Designed in co-operation with SR Drives Limited and manufactured under license it gives unparalleled efficiency across the speed spectrum and incorporates several innovative design concepts. This makes the SR compressor the most efficient variable speed rotary screw compressor in the world.

The SR drive operates on a concept originally proposed at the time when conventional electric motors were first being introduced into industry at the turn of the 20th century. The commercial availability of high power semiconductor components during the last decade now makes it possible to utilize the concept to the full and develop a simplistic, but remarkably effective, variable speed drive system with outstanding efficiency.

SR speed regulated drive system



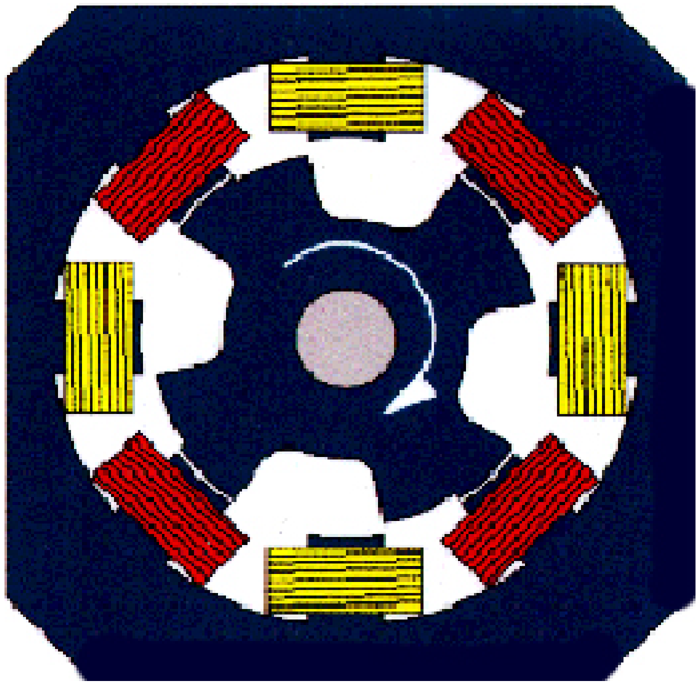
6.0 How The SR Speed Regulated Drive System Works

6. 1 SR Motor

The SR is a two phase DC powered drive unit. Each of the two phases 'A' and 'B' are connected to two sets of four stator windings mounted to the inside of the motor housing. The rotor assembly consists of a laminated steel core with four poles directly connected to the drive rotor shaft. When current is switched on to the 'A' phase stator windings, the resulting magnetic field between the windings causes the rotor poles to rotate and align with the energized stator windings. When the 'A' phase windings are switched off and the 'B' phase windings. By switching the 'A' and 'B' phase windings on and off alternately in a repetitive sequence the rotor can be made to turn. Speed control of the motor is achieved by increasing or decreasing the frequency of which the stator phase windings are alternately switched on and off causing the rotor to rotate faster or slower. The SR motor is capable of operating at speeds between 500rpm and 5000rpm while maintaining optimum efficiency, peaking at 0.934. The SR drive also has torque control which is achieved by accurately controlling the current flow to each of the phase windings by adjusting the length of time and peak current value of each phase sequence pulse.

'A' phase windings energized
Rotor rotates by force of magnetism and aligns to position of minimum reluctance

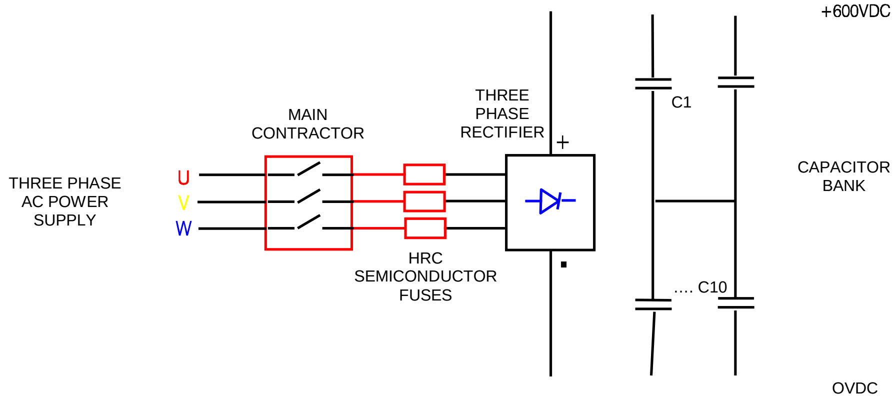
‘B’ phase windings energized
Rotor rotates by force of magnetism and aligns to position of minimum reluctance



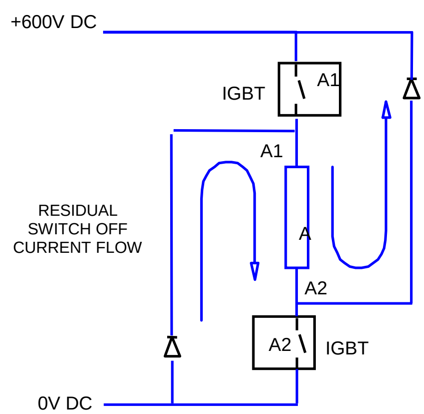
SR Drive Motor

6.2 SR Drive System

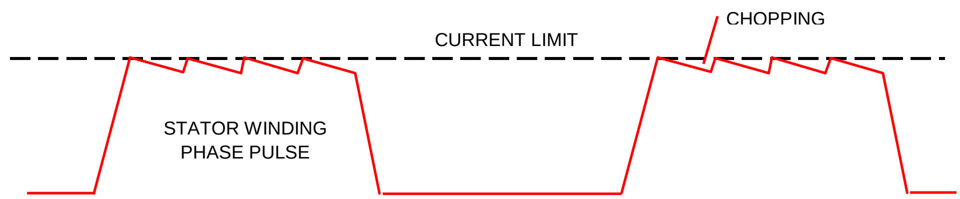
The SR drive unit converts a standard three phase a.c. power supply into a high voltage DC power supply. The a.c. power supply is rectified by six high current diodes to produce a nominal 600VDC. The DC supply is connected to a bank of capacitors which stores the electrical power required by each motor phase pulse eliminating main power supply surge currents.



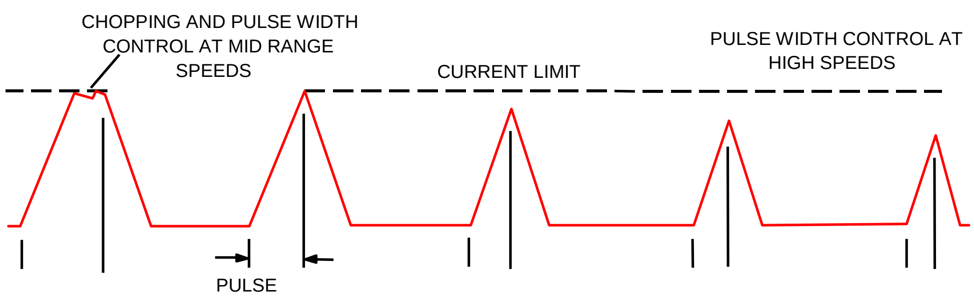
A single main contactor is used to totally isolate the SR drive system when not in use, or in the event of an Emergency Stop situation, and HRC semi-conductor fuses are fitted to protect the SR drive switching system in the event of a fault.



Motor torque and current limiting is controlled by chopping each phase current pulse and/or reducing the pulse width. Phase pulse chopping is achieved by turning one of the phase IGBT switches off when the current level reaches a set limit. Induced back EMF switch off current flow from the motor winding, which produces efficiency losses in a conventional induction motor, is then turned to an advantage and circulated through the second phase IGBT and fly wheel diode causing the phase winding to remain energized for longer. In this manner the back EMF energy is transferred to the motor shaft as useful torque. When the current flow begins to fall the IGBT is switched back on again and the sequence repeated, if necessary, utilizing the second IGBT. At lower speeds the phase pulse may be chopped several times to maintain total control of the torque and current level.



When motor speed increases above 1500 rpm the phase pulses occur rapidly. The natural rise and fall times of the current pulses then begin to limit the peak current levels without the need for repeated chopping. At higher speeds motor torque and current limiting is controlled by adjusting the current pulse width. The shorter the pulse, the lower the current peak value and the resulting motor torque.



To achieve the most effective and efficient phase pulse timing the SR drive controller monitors the rotor shaft position using a position sensor mounted on the cooling fan end of the SR motor drive shaft. Motor current flow and DC drive voltage are also monitored giving real time torque and current limit control enabling a high motor efficiency to be maintained at all speeds.

6.3 SR Drive Initialisation

When power is switched on to the SR drive unit, the drive capacitors are slow charged through current limiting resistors to prevent an initial high peak charging current from damaging the rectifiers or rupturing protection fuses. This is achieved by connecting the three phase a.c. supply through high wattage resistors to the rectifier via a by-pass contactor.

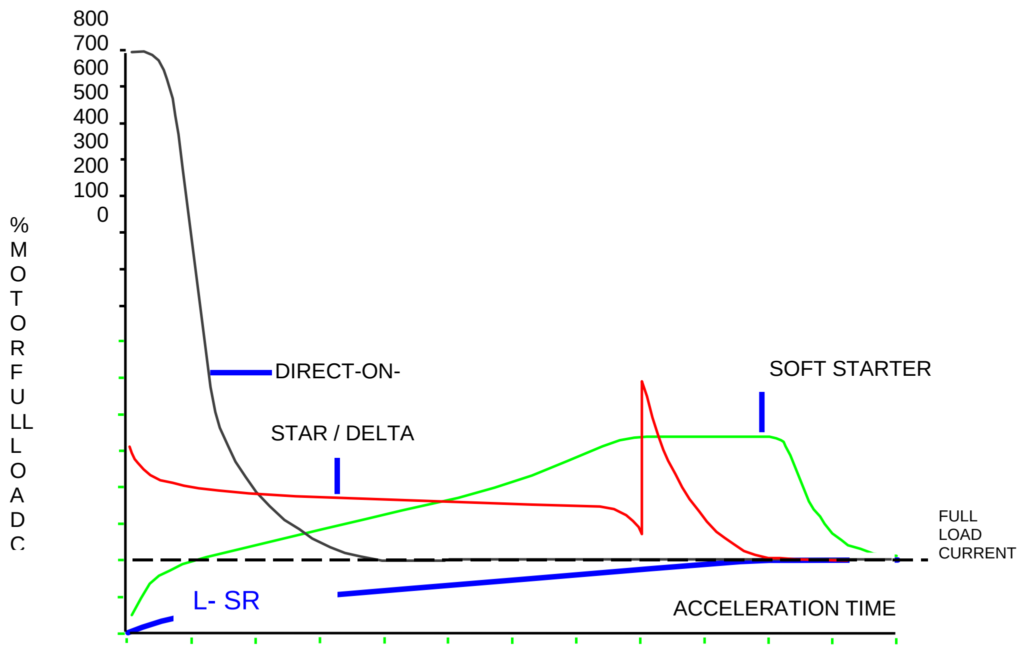
The unique SR drive concept offers efficiency levels unparalleled in the high power variable speed drive industry. This claim can be instantly supported just by observing the SR compressor in operation. The motor runs cooler and quieter than it's conventional counterparts demonstrating that many of the efficiency losses experienced with conventional drive motors have been minimized, and electrical to rotational torque power transfer maximized. Heat and noise, after all, are just detectable forms of power efficiency loss which have to be paid for as part of the normal running costs.

7.0 Unique Features of the SR Drive

The unique SR drive system concept is able to offer other important advantages unachievable with other more conventional drive systems.

7.1 Starting

The SR compressor is inherently soft starting and is able to accelerate the compression element to full working speed in a smooth and controlled manor without any excessive current peak demand. This unique starting characteristic differs from all other motor starter systems, including star/delta, electronic soft starter or frequency inverter variable speed, where the motor starting current will peak at a value which exceeds normal full load running levels.



DRIVE MOTOR STARTING CURRENT

6.2 Run on Time

Eliminating the starting current peak, and resulting heat build-up within the motor windings, prevents the need for a starts-per-hour restriction and energy wasting run-on time, experienced by all conventional induction motor drive systems. The SR drive is able to stop and re-start, as and when required, without limitation or compromise to effective and efficient operation