AN ADVANCED HIGH-SPEED AC DRIVE WITH MAGNETIC BEARINGS FOR FILTRATION SYSTEMS IN GAS COOLED NUCLEAR REACTORS

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INTRODUCTION

In the new design of the modular helium gas cooled nuclear reactors (MHR), the main gas circulator is a large squirrel cage induction motor rated at approximately 6 MW shaft power. This machine circulates the helium gas through the reactor, in which the impeller and the drive end of the motor are submerged in gas of 300°C and pressure up to 7MPa. Traditionally, the circulators have been supplied with oil lubricated bearings. In order to prevent oil egress to the reactor and minimise radiation contamination in the motor compartment, a small proportion of main gas is tapped off, filtered and then pumped back into the motor compartment. This paper is concerned with the motor and fan assembly, the auxiliary blower, which provides the driving force for the filtration gas.

Conventional drives used for filtration systems in nuclear reactors have used cage induction motors which are supplied from either 50 Hz or 60 Hz mains supply. Cage induction motors are preferred because of their high reliability, robustness, low cost, reduced maintenance and long service life. Also, their internal mechanical construction lends them favourably to the submerged gas processing applications. However, there are disadvantages associated with conventional induction motors when operated at such low and constant speeds.

Mechanical constraints and capital costs are significant. For rolling element bearings, limited bearing life is one of the main factors which defines the length of service intervals. The size and weight of both the motor and the impeller are rather large to fulfil the duty requirements compared with a high speed drive. Also, because of the use of direct on-line starting, starting conditions are more severe, with starting currents being several times greater than the full load currents.

There are also performance effects. With a fixed frequency supply, there are only discrete achievable speeds. The optimisation of aerodynamic performance of the impeller is tricky, and often the compromise design is not the optimum one.

This contribution will present some of the results of a development program carried out in the last two years by two Howden Group companies and an independent company which specialises in magnetic bearings, on a high speed innovative AC drive. This drive was primarily intended for submerged gas blower systems in gas cooled nuclear reactors and other similar gas processing systems. A blower comprises of an induction motor, an impeller mounted on the motor shaft and magnetic bearings providing the motor support. The complete unit is submerged in the process fluid (helium). The motor electrical supply is derived from a three-phase voltage source pwm inverter having a frequency range of up to 500 Hz. The paper will outline the contributions of a variable high-speed drive and its benefits when compared with a conventional fixed low speed drive. Particular attention will be paid to the use of magnetic bearings and their effect in relation to the drive performance.

Since the drive speed is controllable by a factor of 10:1, new operational aspects are introduced and some of these are discussed in the paper. Based on the experience gained from this successful work, the paper will recommend the use of high-speed drives for both the present and the next generation of submerged high pressure gas circulators in gas cooled nuclear reactors. This particular development is essential especially for the change from CO_2 to Helium in the high temperature reactors so as to provide the required functionality and reduce capital costs. The components of the drive and the complete system will be shown. The performance of the system will also be presented.

DESIGN ADVANTAGES

A typical application for the new high speed blower system is the gas filtration system used to extract gas, filter it and return it to the gas circulator motor compartment via a shaft labyrinth seal (at the barrier between the motor compartment and the primary loop). It is of particular importance that the filtration system be gas tight and also minimises contamination of the helium. The use of a magnetic bearing system, with no oil or sliding seals, lends itself well to this requirement when submerged in the filtration loop.

In this particular application the duty range for the fan is very much wider than the majority of other gas and liquid moving applications. Typically, fans and pumps handle duty ranges of up to say 4:1. For the new Helium reactors being developed, the duty range is in excess of 40:1, arising primarily from large variations in pressure, hence density and therefore pressure loss (head) through the filter system.

Given that it is uneconomical and impractical to meet the whole of the large duty range, the optimum solution for the blower system was to select a motor which could deliver a 10:1 speed range with a power of around 10kW. Though this does not cover the complete duty range, it is adequate for this application and very much better than was available previously with fixed speed machines. Additionally, around ten times the through-put of gas is available with this new blower system, dramatically improving the performance of the filtration system.

The motor for such an application had to be of an extremely compact design to ensure maximum benefit, without the use of materials susceptible to radiation damage or pickup. A 10 kW motor had already been developed for submerged helium use in the nuclear environment and so the 10kW motor from Airscrew Howden was an obvious choice for this application.

The predecessor of the current blower system was designed and built specifically for the helium environment, but employed gas dynamic bearings. However, the design life for that application was far short of the 40 years required for the MHR. That design has been modified to incorporate the latest technology in magnetic bearing design. The benefits of this are both in terms of reliability and functionality.

The life target of 40 years could only be met with the use of magnetic bearings. Rolling element bearings require maintenance every few years while gas dynamic bearings have a very limited stop/start cycle and consequently lower availability. The alternative to gas dynamic bearings, gas static bearings, require a high pressure blower of their own which in this environment is counter productive.

From a functionality view-point, the use of magnetic bearings allows virtually any motor speed, and speeds very much higher than with the conventional drives. There is a significant shaft power saving using magnetic bearings over sliding or rolling element bearings and there is also a significant power saving from operation at best fan/motor efficiency for any duty selected. In addition, with variable speed, operational aerodynamic instabilities such as stall and surge can be eliminated.

The plant associated with the new high speed blowers becomes significantly smaller, as both the motor and the fan become smaller. The overall reduction in size therefore leads to a corresponding reduction in cost.

INVERTER-FED INDUCTION MOTOR DRIVE

It is evident that in the MHR, the use of variable speed drives for both the main gas circulator and the filtration system offers several benefits over the existing fixed speed drives. High speed submersible induction motors of special construction lend themselves favourably to these applications.

Inverter-fed induction motor drives can operate in closed or semi-closed loop control modes. At present, closed loop control requires a means of sensing the motor speed directly from the motor shaft. However, direct motor speed sensing is less reliable for operation in submerged conditions which involve both high pressure and high temperature.

An inverter-fed induction motor drive is ideally suited to a variable speed submerged blower system. The drive provides soft-start and ramping facilities which eliminate all problems of high starting current and over stressing the machine during starting periods. The physical size of the drive is much smaller and either closed or semi-closed loop control is achievable from a remote point using new analytical techniques. The drive regulates itself and can be made to supply just sufficient power at an optimum duty point thereby saving power and extending system life. Maximum efficiency of the system can only be attained if the induction motors are operated at variable speed and is achieved by *constant slip* operation over the supply frequency range.

PERFORMANCE ANALYSIS AND SPEED PREDICTION

Drive Performance Analysis The inverter-motor drive comprises a 3-phase, voltage source PWM inverter supplying a 3-phase, cage induction motor as shown in Fig. 1. The voltage and current waveforms of the PWM inverter are rich in harmonics and are also non-sinusoidal. The time harmonic currents at harmonic frequencies have detrimental effects on the overall performance of the motor in terms of increasing motor losses and producing noise and vibrations. The orders and magnitudes of the time harmonic currents are directly related to the type of the pulse-width