Customising for competitiveness

Integrated and off-standard designs

2212E

BROOK CROMPTON

Introduction

Trends in the motor market

The last decade has seen fundamental restructuring of core OEM (original equipment manufacturer) industries across Europe. Acquisitions and mergers have individually hit the headlines, but the underlying trend has been one of creating international OEM industries, with multi-national players becoming dominant in almost every key application for electric motors. Bigger players, higher volumes, scale economies, lower costs and a more competitive arena is the result.

Those which remain in the mainstream equipment markets are innovating in many ways to cut costs. Product designs are changing accordingly and so are the motors that drive them. Product lifecycles are shorter and so motor manufacturers must be more responsive with their specifications and ability to customise in new ways. In addition to improving performance, adaptability and value of standard motors, the ability to work with OEMs in providing integrated motorised products is increasingly important.

Integrated motorised products are now dominating their industries in applications as diverse as water circulators, fans, high-pressure washers and drainage pumps. This is no longer just the case in fractional motors in domestic equipment, but is increasingly so in higher-powered industrial products. By taking a total engineering perspective of the driven equipment, motors can be integrated and optimised to eliminate interface materials and costs, reduce space, cut assembly time and add end-user value, for example, with increased efficiency or lighter weight.

The integrated motor in practice

The concept of integrated motors in industrial plant is not new. For over 3 decades, refrigeration compressors with fully integrated stators and rotors have dominated the high volume core of their market.

This arrangement is not just a mechanical integration saving on components, weight and cost. It is also a thermally balanced piece of equipment, the motor being cooled by the refrigerant surrounding it. This in turn enables a higher output rating to be allocated to the motor and hence a smaller motor is used than the air-cooled equivalent.

Integrating motors into pumps has resulted in the success of the submersible pump, for example in sewage or drainage pumping.

Here the rating of the motor is dependent on the cooling arrangement. When continuously submerged, the motor rating is higher. However, the main benefit achieved is cost reduction over previous pumping arrangements, which required a line-shaft to the pump to be driven from a pit alongside the sewage tank, or from a pontoon carrying the motor above the water surface.

The fully integrated submersible pump requires only the electric supply cable and out-flow pipe to be connected.

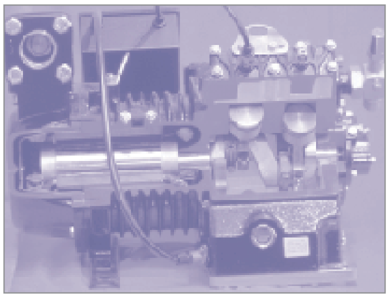

Fig 1 - stator and rotor components mounted inside a refrigeration compressor

Another prime example in water pumping can be seen in the common glandless water circulation pump. In this arrangement the water is allowed to circulate in the 'canned' gap between rotor and stator, hence providing the cooling medium. Typical insulation systems allow motor temperatures to rise to over 150°C, hence even hot water near to 100°C, provides effective cooling.

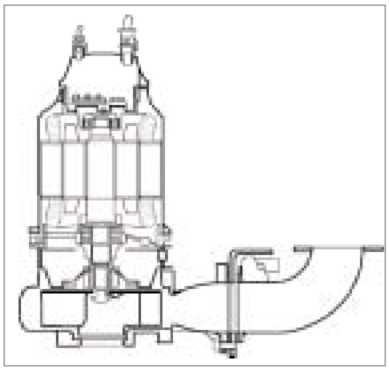

Fig 2 - integrating the motor into the pump facilitates a fully submersible pump

This design eliminates the need for mechanical seals between the motor and pump, a source of cost and wear. The design is also more compact and saves on materials at the interface.

Commonly, speed control is added to the equipment, perhaps by voltage taps from the windings enabling different pump speeds and hence water flow rates and pressures to be achieved. Modern inverters can provide a fully variable speed arrangement. These are increasingly available as integrated motor/inverter combinations.

Another type of mass produced pump, the piston pump used in high pressure washers, has also moved towards the use of customised motors to reduce interface costs. These pump units are typically supplied with a male drive shaft, which would traditionally be driven by the motor via a coupling, possibly in a ‘bell-housing’ at the motor/pump interface. In a low volume engineered product this would be deemed as a well configured arrangement making use of largely standard components. However, in a highly competitive volume market, unit cost reduction becomes more crucial and customisation more attractive. The alternative engineering perspective of a ‘motorised pump’ as opposed to a ‘motor coupled to a pump’ would question the need for 4 bearings, 2 shafts, the coupling, the bell-housing and the peripheral costs of mounting and enclosing the bulky arrangement.

In the arrangement opposite (Fig 5), a customised motor provided a hollow shaft to accommodate the pump unit shaft. The motor drive-end bearing was dispensed with and an endshield provided to match the fixings on the pump. The result was a saving of the coupling, bell-housing, one bearing and considerable space and weight. Note also the on/off switch located into the terminal box.

Some high pressure washer manufacturers have taken the concept further by a well designed plastic casing around the whole unit.

Commercial fans, particularly cased axial flow fans, have made increasing use of different motor geometry in recent years. Pedestal foot or rod mounted industrial motors are generally mounted centrally in the air stream with the fan impeller hub mounted on the motor shaft. The length of the unit is therefore determined by the (motor and hub) axial lengths. One option has been to mount the hub on the outside of an external rotor motor resulting in a considerably shortened fan unit. However, this suffers drawbacks of lack of adaptability to different hub sizes and can be difficult to seal for a weatherproof or hoseproof IP55 enclosure. More compact internal rotor designs are available with significantly shorter lengths and geometry to enable the shaft mounted hub to wrap over the motor frame. This provides increased flexibility of motor/impellor combinations whilst easily affording IP55 protection.

The benefits achieved by applying shorter motors can include:

- shorter case
- lighter total unit
- easier to package and distribute
- easier to assemble
- better motor cooling, hence higher outputs

Whilst it is apparent that the motor profile is taking up more of the duct area than in former designs, in practice:

- most of the air movement effect is towards the outside of the impeller
- air scrubbing, hence cooling of motor is enhanced

Parameters for motor integration

Clearly the use of a non-standard motor can result in a higher initial component outlay for the equipment manufacturer.

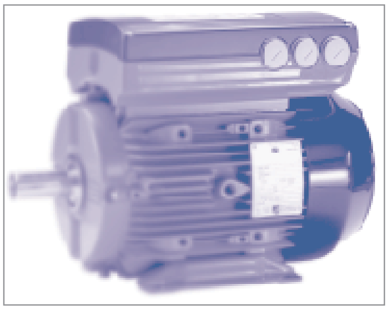

Fig 3 - integrated variable speed motor incorporating an inverter

Digression from a standard motor must offer advantages to offset the higher price and manufactured lead time instead of ex-stock availability. As can be seen above, many benefits can be derived. The objective of the design engineer must be to assess all the key parameters relating to the total motorised equipment to optimise the design.

Fig 4 - traditional method of assembling pump and motor

Fig 5 - this female shaft arrangement eliminates the need for a coupling and a ‘bell-housing’

Methods of driving cased axial fans

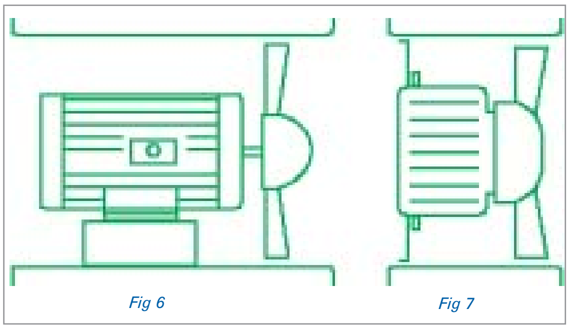

Fig 6 - standard industrial motor
Fig 7 - dedicated fan motor

The parameters to consider might include:

Parameter	Possible Benefits
Space saving	• less cowling or smaller equipment covers • smaller base plate or mounting • lower cost packaging, transport and storage
Material reduction	• cost reduction • weight reduction • environmentally friendly
Energy efficiency	• sell benefit of lower user costs • reduced cable size • reduced cost controls • less heat to dissipate • environmentally friendly
Time saving	• reduced assembly time • reduced installation time • lower maintenance demands
Reduced inventory/ componentry	• reduced capital costs • simpler spares servicing • fewer failure modes
Improved aesthetics	• easier to sell

As previously shown, there are many proven ways of integrating motors to a greater or lesser extent to achieve some or all of the above benefits. These motor variations can be considered in 3 basic categories:

- simple modification
- off-standard designs
- fully customised designs

Simple modifications

Changes to the basic cage induction motor that may offer benefit to the equipment include:

- flange or face mounting in standard or non-standard sizes
- remove the fan and cowl (eg for use in fan duct)
- rod or pad mounting, for mounting in a fan duct
- change terminal box position

Off-standard designs

More radical design adaptations might include:

- customised shaft extension, eg to fit smaller first pinion in gear box
- customised drive endshield for optimised mounting
- special fan cover to direct air over both motor and driven equipment
- special electrical characteristic (eg 2-speed motor) for added flexibility

Customised designs

- shorter motor
- low centre motor (eg for saw bench)
- special frame casting to mount equipment components
- frameless motor (stator-rotor) unit
- dedicated motor interior for special performance
- complete re-configuration, eg axial airgap motor

Fig 8 - mechanically adaptable motors offer choice at low cost

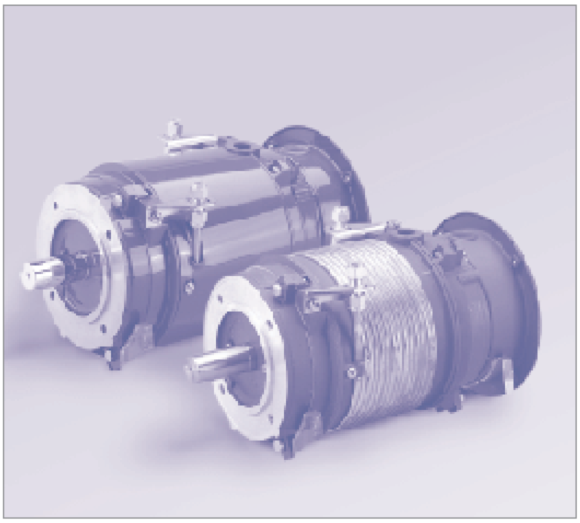

Fig 9 - mechanically adaptable motors offer choice at low cost

Integrated motor design limitations

The opportunities for motor integration may be limited by one or more engineering considerations:

Thermal
The motor will produce heat proportional to its efficiency and rating. Cooling must achieve thermal equilibrium without the motor winding exceeding its insulation temperature limit (155°C for class F insulation), or exceeding critical bearing temperatures. In the integrated design there may be other heat sources (eg compressor), which require an understanding of the total thermal model of the equipment. Clearly, little cooling will be harmful whilst excessive cooling will be energy wasting and in the case of air-cooling, excessively noisy.

Electrical
Putting together 2 electrical devices (eg motor and inverter) usually means combining 2 heat sources resulting in thermal consideration as above. Electromagnetic interference, especially under new EC Directive (89/336/EEC and 92/31/EEC) may also be important. However, significant benefits of reduced wiring and installation requirements may be available to offset the disadvantages.

Mechanical
Ideally, motors should be kept as vibration free as possible. Direct mounting and coupling may cause enhanced vibration transmission and reduced life. Clearly, the means of mounting and shaft coupling must account for the realistic torque between stator and rotor. Under direct-on-line (DOL) conditions, these torques can be as high as 250% of full-load torque under start up.

Assembly and maintenance
Component and material cost savings must not be lost in added labour costs for assembly, hence 'design for manufacture' principles should ensure that the integrated unit is easy to assemble consistently. The long term maintenance needs of the equipment should also be considered if the market attractiveness of the equipment is not to be diminished. A realistic assessment of whether the cost reduction of the equipment has achieved the status of 'disposable', ie not economically viable to attempt to refurbish in the event of field failure or reject. Clearly the knock-on impact on distribution and service infrastructure requirements may in itself result in a new business model for the product. Note the availability of compressors and high pressure washers direct to the public via DIY stores, for example.

New technologies, new choices

Opportunities for improved engineering of OEM products through integrated motors will be enhanced as a number of new and improving technologies become available, these include:

- plastic composites with better rigidity and stability under higher temperatures
- improved casting techniques enabling fewer components in more creative shapes
- better electrical steels resulting in higher efficiencies and lower thermal constraints for the motorised units
- permanent magnet technology providing much higher performance motors
- new shapes in motors, a key example being the axial airgap motor
- new electrical insulation materials for the new generation of high performance inverter drives

Axial airgap motors

New dimensions, new opportunities

The axial airgap motor has disc-shaped stator and rotor cores which are placed adjacent to each other with flux linkage across an axial air-gap. Established electromagnetic and induction motors theory leads to the production of torques as a result of electric energy input, but the configuration of parallel stator and rotor requires a radically different method of construction.

The axial airgap motor concept is not new. It was invented in Switzerland during the late 1940s and over the years it has been developed for a variety of applications, one example being as a fractional horse-power motor in a fish-pond pump.

Axial airgap motors in fractional horsepower applications

In the photographs (see right), the motor shows how a compact pump unit can be produced cost-effectively, making use of the opportunity presented by the shape of the motor for the isolation of the stator winding. The pump is a centrifugal type relying on a relatively flat impeller.

As with the examples of integration of the cage induction motor discussed earlier, there must be a total engineered view of the motorised product rather than separate designs of pump and motor. The thermal consideration in this instance would take account of the pump unit being immersed in water with a predictable ambient temperature, a medium which of course passes through the pump, improving heat transfer.

Electrically, the unit is a fixed speed device which can be optimised accordingly. The design engineer may take account of the favourable thermal conditions and optimise the active material content. Mechanically, the axial airgap motor presents its own problems in terms of stator-rotor thrust. The direction of rotation may enable the axial pump thrust to slightly offset the magnetic thrust and the bearings are selected for use immersed in water. Assembly and maintenance are clearly assisted by the apparent pragmatic choice to perceive the products as disposable. Compound injected into the plastic casing seals the stator and provides rigidity but renders it irrepairable.

Axial airgap motors and design constraints

Clearly, many of these design techniques are very relevant to fractional horse-power (FHP) applications. In taking the motors beyond the FHP arena, design constraints emerge which have so far prevented the axial airgap motor becoming a realistic design option in high volume industrial applications. Because of this, until recently, the volume production techniques which would ensure product viability as an industrial motor have remained undeveloped.

Design considerations for axial airgap motors

Axial airgap motors have similar design criteria to other ac electric motors, but there are specific considerations:

Thermal

Since the axial air-gap stator presents less surface area as a proportion at its volume in direct contact with a heat transfer mechanism, then in one respect it is at a disadvantage when compared with a conventional squirrel-cage motor with its diecast aluminium ribbed frame. However, the geometry and position of the rotor makes it more accessible for dissipation of the rotor losses which are buried at the heart of a conventional motor. Taking these factors into account, it is possible to achieve designs with competitive output coefficients.

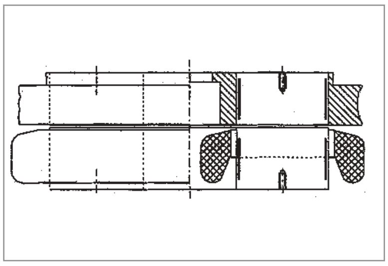

Fig 10 - axial airgap motor components

Fig 11 - axial airgap motor driven fish pond pump

Fig 12 - the axial motor integrated within the pump

Electrical

The creation of laminated cores for the stator and the rotor of axial airgap motors of differing electro-magnetic designs can be achieved with less capital investment than a conventional squirrel-cage motor. This provides the opportunity for the electrical designers to prepare optimised designs for specific high volume applications, without any compromise which would apply where the lamination stamping for a conventional motor was rationalised to cover many varied application requirements.

Mechanical
A significant axial force is developed between the stator and rotor when energised. The force of attraction acts to close the working air-gap between the two components and is a principle consideration in the mechanical design of a full motor which utilises the axial airgap technology. Methods which have been adopted are the use of twin rotors or stators to create equal and opposite attraction forces which cancel out, or to adopt a bearing arrangement capable of accommodating the force.

Inertia
The geometry of the rotor core of an axial airgap motor, being disc-shaped, leads to a substantially higher rotor inertia than would be experienced on a conventional squirrel-cage induction motor of equivalent rating. This could be of advantage where a flywheel effect is desirable, but must be borne in mind where fast response upon starting or breaking is required.

Manufacture of industrial axial airgap motors

Given that there was previously no known volume manufacturer of industrial axial airgap motors, establishing a manufacturing plant at Brook Crompton near Birmingham, was a challenge to the various parties concerned. However, this is operational and has been supplying industrial axial airgap electric motors for a number of years. Inevitably under such pioneering circumstances, there were lessons to be learnt as the process was refined. However, Brook Crompton selected an automated process from the outset, ensuring that excessive labour costs were not necessary and achieving consistency of product, for the volume OEM market.

Unlike the squirrel-cage induction motor, of which both stator and rotor are built on stacks of individually- punched steel laminations, the axial airgap cores are produced from a tightly formed coil of steel strip. Close control at the coil rotation in relation to a slot punching operation leads to the creation of slots, which can be arranged to be radial or skewed as required.

For the stator, coils of copper wire are inserted into the slots and connected to form the winding, whereas for a rotor, the aluminium conductors are created by die-casting.

The stator and rotor cores are the principle elements of the motor, which can then be combined with an enclosure, shaft, bearings etc consistent with the mechanical requirements of the application.

Industrial axial airgap motors - commercially viable?

As in any volume induction motor (and not dissimilar to any other manufactured product), the key cost components are materials, direct labour then variable and fixed overheads. The criteria for potential success of the industrial axial airgap motor is considered to be cost-competitiveness (though not necessarily cost parity) with the volume squirrel-cage induction motor, with any cost differential being potentially more than compensated for by cost savings or added value in the overall driven equipment.

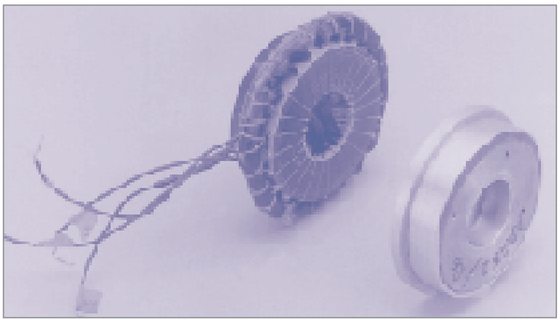

Fig 13 - axial airgap motor, wound stator core and diecast rotor core

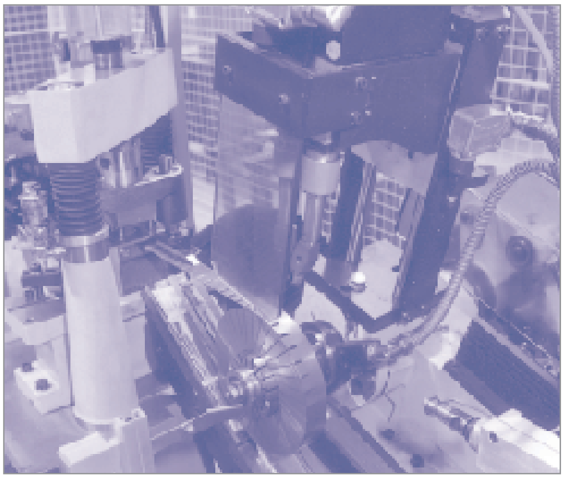

Fig 14 - axial airgap motor core manufacture

Brook Crompton's findings are:

Material costs
The geometry and the manufacturing processes associated with the axial airgap motor lead to more effective use of active materials and less wastage. However, the high thrust loads require more substantial bearings than would be found on a conventional radial airgap machine of equivalent rating. Together with the increases incurred as a result of available purchase quantities, (standard cage induction motors are now manufactured in high volumes by manufacturers with economic purchasing strength), component costs can be higher. Therefore, output for output, the material cost content is similar to that for the equivalent standard motors.

Labour costs

Clearly this depends upon the extent to which reliable automation can match the processes now available for radial airgap cage induction motor manufacture. The Brook Crompton process has tooled for the volume OEM demand. Low demand individual requirements are not considered at this stage.

Overhead costs

The choice to tool-up for volume production clearly requires significant upfront capital investment and therefore ongoing depreciation costs. However, these are not dissimilar to the equivalent investment costs for volume manufacture of radial airgap motors. Upfront engineering costs have been an inevitable consequence in the pioneering situation of establishing a first production cell. In summary, therefore, the industrial axial airgap motor can be viably manufactured as a volume product for OEM markets.

Potential applications for the industrial axial airgap motor

The key benefit offered by the axial airgap motor is short axial length. It offers the OEM design engineer new scope and new opportunities to re-configure the driven equipment around an integrated electric motor where radial airgap motors have been a constraint. Clearly, its successful application must achieve competitive advantage for the OEM product in its market place, perhaps due to compact design.

Conclusion

Competitive pressures and the opportunities of higher volumes from fewer but larger manufacturers are driving innovation in industrial equipment design.

Taking a total engineering perspective of both equipment and motor may show benefit in integrating a customised motor. Cost, weight and size reduction, performance and specification enhancement are possible outcomes.

Developing technologies in electric motors provide new opportunities for the equipment manufacturer. One of the most significant may be the availability of axial airgap motors in industrial sizes.

The industrial axial airgap motor is a commercially viable proposition for the volume equipment OEM designer. Design, manufacturing and cost constraints can and have been overcome in ratings as large as 2.2kW. It offers opportunities to exploit short axial length in the driven equipment, which may add engineering or marketing benefit to the total motorised unit.

The current engineering constraints are likely to be pushed upwards enabling higher ratings to emerge in future.

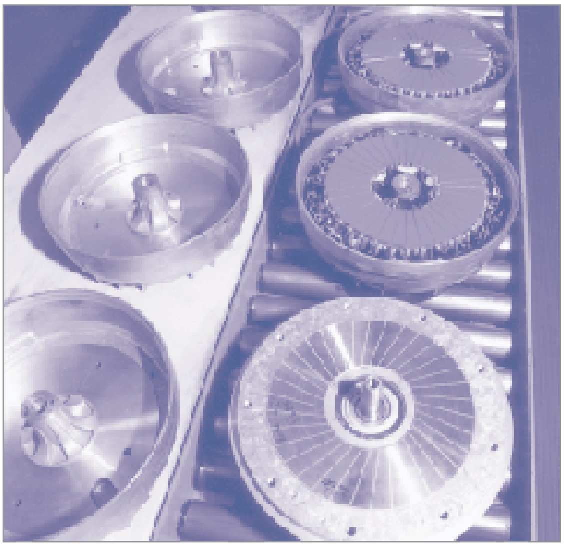

Fig 15 - axial flux motors prior to assembly

Customised motors from Brook Crompton

Brook Crompton offers extensive experience and capability to engineer electric motors for the high-volume equipment manufacturer. It is one of Europe's market leaders in industrial electric motors.

The award winning 'W' range offers world leading mechanical adaptability and hence the ability to provide non-standard motors at little extra cost. In-house manufacturing encompasses lamination stamping, casting, machining of shafts and frame components, winding, assembly and test.

Brook Crompton is pleased to discuss customer requirements in confidence and assist in optimising motor designs to the driven equipment.

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