Alternative Bearing Systems

It is an unavoidable fact of life that viscous drag in the bearings of a turbocharger prevents a significant proportion of the power developed by the turbine from being 'translated' into worthwhile output from the compressor. At low turbo speeds this effect is more pronounced, contributing to turbo lag.

At a time when any improvement in overall turbocharger efficiency can contribute critically to an engine's ability to meet more stringent emission limits and performance targets, even modest percentage reductions in viscous bearing drag become technically attractive.

There are numerous emerging bearing system technologies, which at the cost of extensive development programmes, are poised to one day take over from the typical hydrodynamic floating ring bearing used in today's mass market automotive turbochargers. Together with the axial thrust bearing, it has remained an intrinsic feature of Holset's turbocharger range since the 1950's.

To describe the floating ring bearing as simply 'a metal ring of some axial length with radial holes' is reasonably accurate, but tends to trivialise the complexity of the design. The main purpose of the floating ring bearing (see fig 1) is to create an inner and outer oil film, so that the shaft journal surface is constrained radially within the bearing, which in turn is constrained radially by the housing. The floating ring bearing is designed to rotate at a fraction of rotor speed, which allows the rotor system to remain stable at high rotational speeds that would normally lead to instability in a plain journal bearing.

In contrast the axial thrust bearing (fig 2) is a relatively simple device that develops a hydrodynamic load due to the 'wedge' created by the geometry of the tapered pads and the load carrying surface of the thrust collar and oil slinger. Oil is dragged into the wedge under the influence of viscous forces and because the oil is incompressible, pressure builds up and hence the load is generated.

Why do we want to change floating ring bearings and axial thrust bearings?

Today's floating ring bearings and axial thrust bearings are very cost effective to produce. Dimensional tolerances are easily controlled, given modern manufacturing methods and they deliver an acceptable performance for the present generation of diesel engines. Also, they provide good shaft motion control with proven reliability and durability. However, tomorrow's high performance, low emission engines are almost certain to demand higher turbo efficiencies. Meanwhile the advent of a quite new bearing technology will offer the opportunity to address secondary issues like oil leakage, blowby and noise generation from out of balance and sub-synchronous vibrations that beset some current turbo installations.

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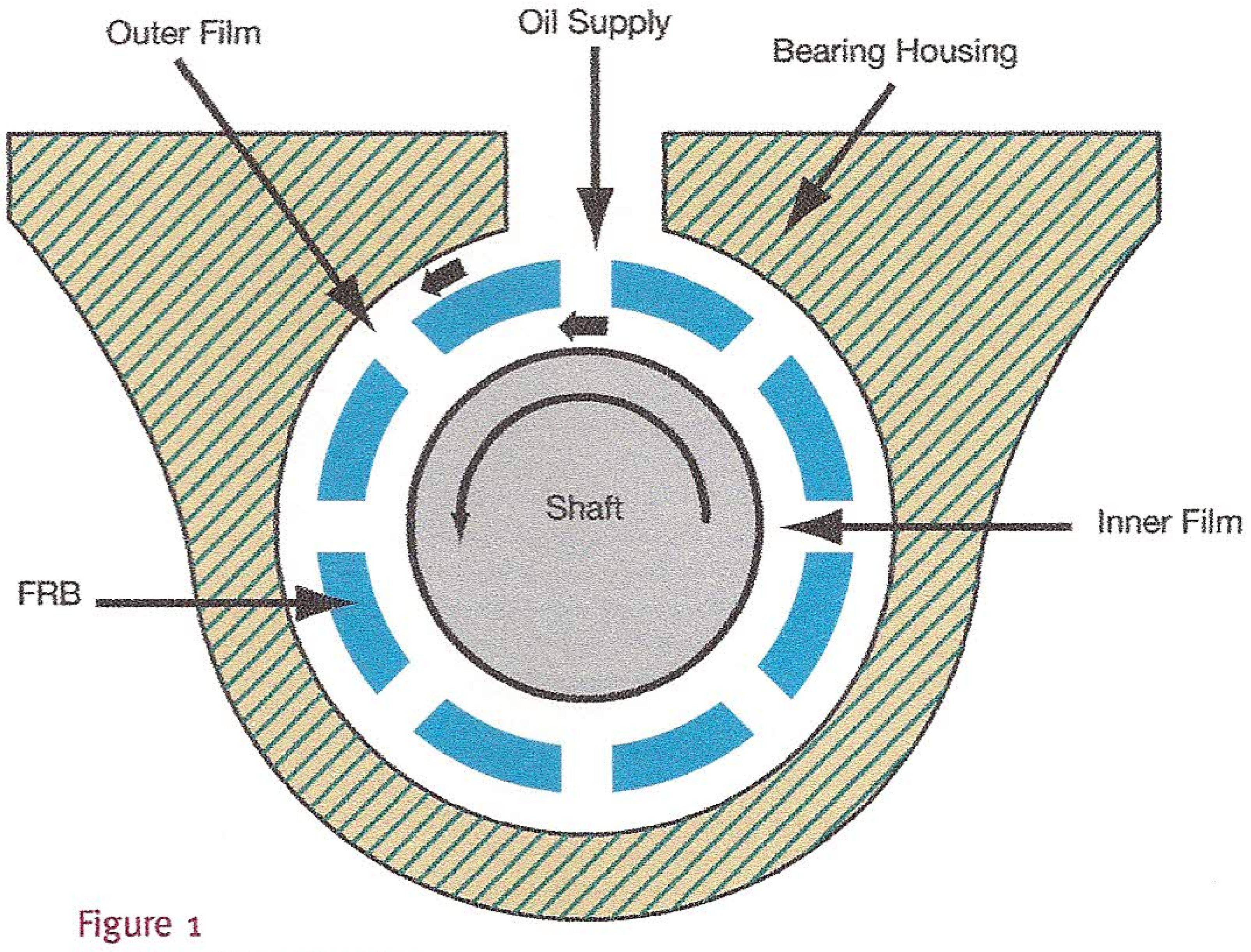

Figure 1
Floating Ring Bearing

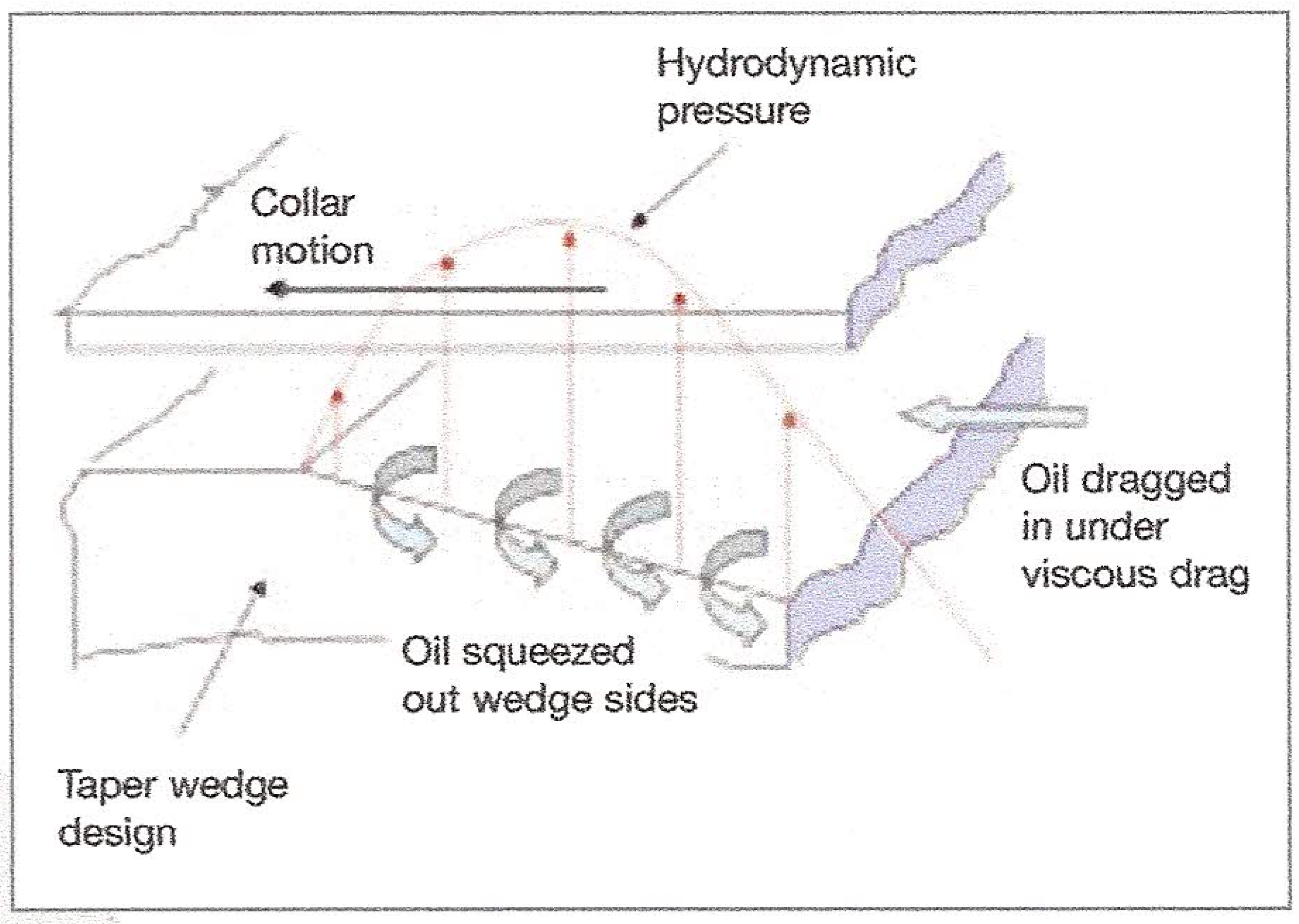

Figure 2 Axial Thrust Bearing

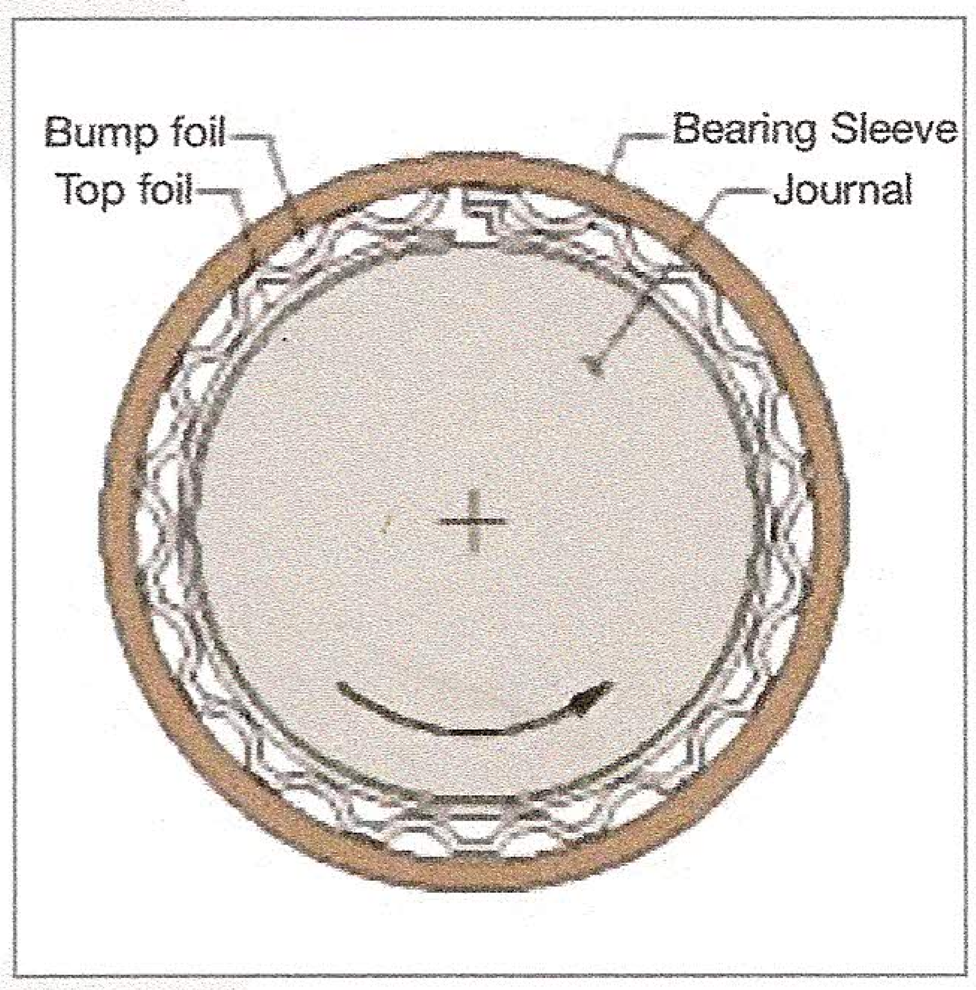

Figure 3 Air Foil Bearing

Where do we go from here – what are the options?

Bearing systems offering potential advantages over current designs include:

a) Hydrodynamic air bearings use air as the 'lubricant' separating the adjacent bearing surfaces. Among the technology challenges are the needs, at considerable extra cost, for very small clearances and the probable use of ceramic in place of metal materials. However, they have been shown conclusively to deliver the key benefit of very low parasitic drag.

b) Airfoil bearings (fig 3) consist of a compliant spring-mounted metal foil that wraps around the shaft surface. Parasitic losses are commendably low, but initial start-up friction and associated wear pose a significant technical challenge given the extended durability demands now made of turbochargers.

c) Rolling-element designs typically feature deep-groove ball bearings with ceramic balls and ceramic or metal races. Parasitic drag would be significantly reduced, but rolling-element bearings are unlikely to match current floating ring bearing durability standards.

d) Hydrostatic bearings require a high pressure gas to maintain the clearance between two surfaces. Durability is expected to be excellent, parasitic losses are low and small aerodynamic clearances can be maintained.

e) Active magnetic bearings (fig 4) use an electronically-controlled series of magnetic coils at each bearing station to centre the shaft precisely. This offers the prospect of very low vibrations, with correspondingly low parasitic drag.

Spoilt for choice?

There is no single factor that makes any of the above options an obvious choice. Holset has accordingly applied a technique known as Quality Function Deployment (QFD). It involves a detailed evaluation of the design features of today's floating ring bearing and axial thrust bearing turbo bearings, allocating to each a plus or minus value depending on its respective degree of advantage or disadvantage to the finished product. It was necessary to group those factors into various categories, according to their different levels of importance attributed by particular OEM customers.

Bearing durability and reduced noise continue to dominate many OEM customers' expectations, which often correlate with numbers of warranty claims. Within this category, specific issues include:

Sub-synchronous noise: vibration attributable to fluid (oil) film instabilities.
Once per rev noise (or synchronous vibrations): due to imbalance.
Degree of imbalance tolerance: related to available machinery and manufacturing process capability.
Emergency failsafe: consequences of mechanical failure.
Cooling: efficiency of oil's cooling medium role.
Dirt tolerance: critical to bearing durability.
Thermal effects: local 'hot spots' can affect stability and durability.

In addition, the following bearing-related issues can arise under sustained high performance conditions:

Motion control: affecting aerodynamic clearances.
Parasitic viscous losses: potentially impairing overall efficiency.
Oil leakage into air or gas flow: adding to engine's particulate emissions.
External control: bearing configuration affected by external power source, for example, electric motor drive (see article on page 11).

Risk assessment: is the proposed new bearing technology already established in other applications?
Current: is there an example in current technology of the application of the system?
Future: possible technical risks must be considered and evaluated.

The ever present COST factor

Among the cost and added-value factors needing to be considered are:

Bearing system: the cost of new and innovative bearing components eg ceramics, and related surface tribology (friction) control.
External control: the additional cost of an external drive system, probably requiring magnetic or hydrostatic bearings.

Conclusions

Perhaps not surprisingly, Holset's extensive bearing analysis programme suggests that the well proven floating ring bearing and axial thrust bearing designs continue to perform well in today's turbocharger applications. Achieving the levels of bearing performance in current turbo rotor systems using alternative bearing technologies and at an acceptable on cost remains a formidable challenge. Holset is accordingly embarking on a series of R&D projects aimed at improving, especially in durability terms, those floating ring bearing and axial thrust bearing types of bearing, without significant increases in cost.

At the same time, those ever present goals of enhancing turbocharger performance and reducing noise and vibration will not be neglected. This requires a holistic approach, through the integration of the design and manufacturing processes, making use of computer based tools, such as 6 Sigma quality methods (see article on page 13).

Where unprecedentedly high turbocharger performance is demanded in the future, Holset envisages, in the light of its bearing technology study, some form of magnetic bearing system as the most promising alternative to current floating ring bearing/axial thrust bearing configurations. Apart from the more obvious advantages of low parasitic losses and potentially reduced aerodynamic clearances, magnetic bearings promise reduced blow-by and virtually no oil leakage. However, incorporating the electrics and electronics associated with a magnetic bearing system into a turbocharger's high temperature, vibration prone operating environment poses a significant engineering challenge. The technology is likely to emerge only if and when legislation or market pressures demand it.

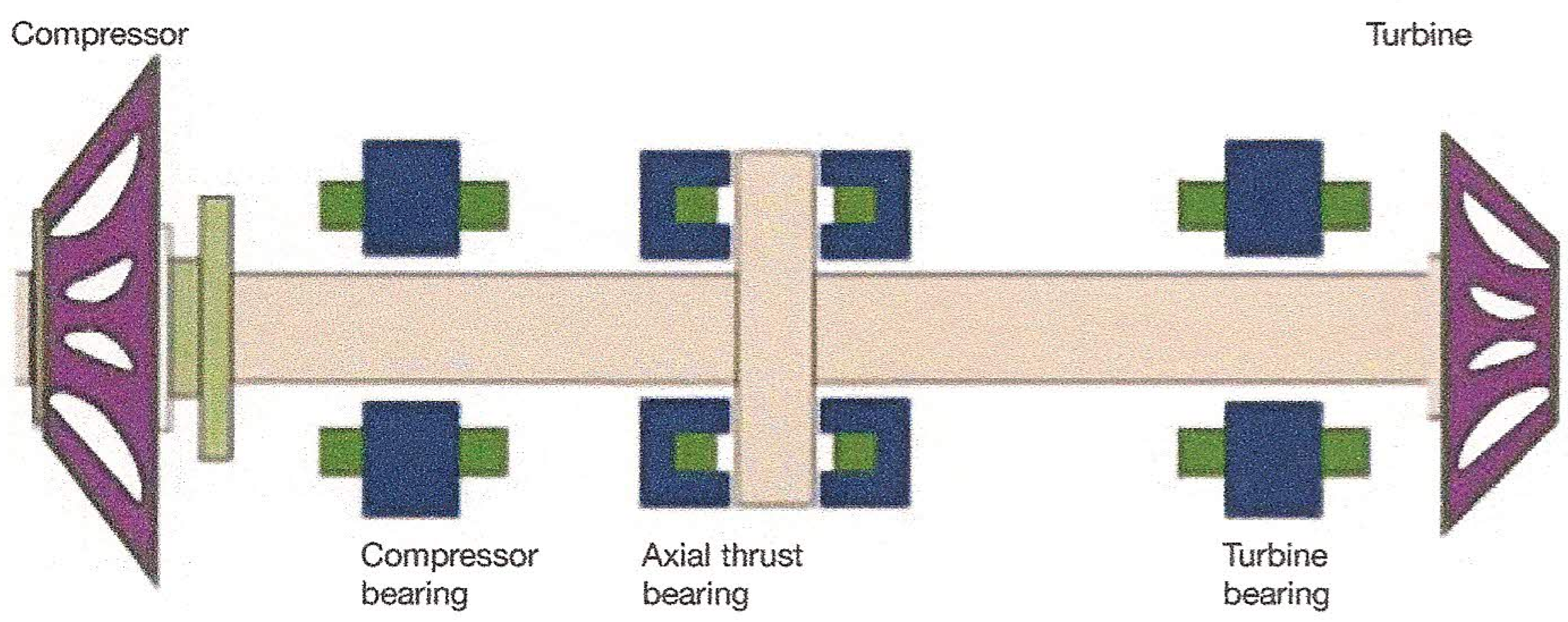

Figure 4 Active Magnetic Bearings