DIFFUSION OF MAGNETIC BEARINGS

THE MARKET IS IN A SPIKE AS END-USERS LEARN ABOUT THE ADVANTAGES AND WITH THE INTRODUCTION OF THIRD GENERATION TECHNOLOGIES

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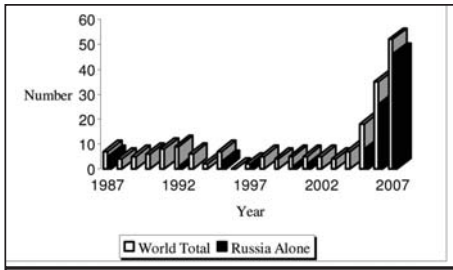
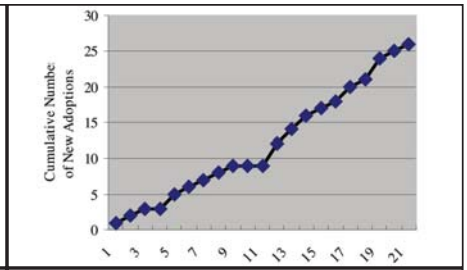
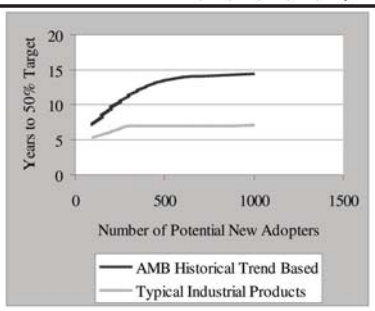
The diffusion of new technologies into industrial and consumer goods market has been studied extensively over the past four decades. This effort has given rise to several useful mathematical model formulations that describe the diffusion process as one by which users will substitute an older established technology with a newer one on the basis of how efficiently communications about the newer technology's attributes, risks, and costs are enabled.

The drivers for the penetration of Active Magnetic Bearings (AMBs) have been promoted extensively. They are: Reduced power losses, reduced maintenance costs, wider operating speed and temperature range, better rotordynamic control, lower fire risk, less expensive foundations, and so on, while achieving reliability and availability figures that are at least as good as oil lubricated bearing systems, and with a justifiable price premium.

These positive attributes can therefore be expected to facilitate the penetration of Active Magnetic Bearing (AMB) technology into this large turbomachinery in a systematic way that can be described accurately by a mathematical model. This would allow the prediction of the rate at which the technology would be adopted as well as what fraction of the population of ultimate adopters will adopt at what time.







Clockwise from top
Figure 1: Total number of applications of Active Magnetic Bearing technology by year
Figure 2: Cumulative number of new adoptions over two generations (Year 1987 = 1)
Figure 3: Years to 50% adoption target of new adopters by simulation showing inefficiency of present communications

Picking up more speed

The first generation of AMB technology as applied to large turbomachinery appeared in the mid 1980s. It was characterized by analog electronics, relatively low power output amplifiers that drive current to the magnetic bearing windings, and simple stator mounted ball bearings that served as the machine protection in the event of loss of stability or internal system failures. A significant number of applications were undertaken with this technology in large turbomachinery, especially compressors, in Europe (including Russia) and North America.

Important applications to other large rotating equipment, including turboexpanders, turbine generators, and pumps have also been made. But the applications to compressors, whether driven by gas turbines or electric motors, is chosen for this study because the large number of applications to this class of machinery provides a statistical basis for the study of AMB diffusion process characteristics. Moreover, compressors typify the application of AMB technology to other large turbomachines.

A typical example is shown in Figure 1. Note that the salient figure of merit when examining adoptions of the new technology is not the number of adoptions by the original equipment manufacturers that use bearings in their compressor designs. Rather, it is the number of adoptions by end-users to whom the financial and operational benefits accrue.

Figure 2 displays the cumulative number of applications during this time period (pre 1995 error band: ±1 year) by end-users in large compressors above 2 MW power rating. An impressive upswing in new applications begins in 2004, especially in Russia. Like the other plots that follow, this chart includes the known applications of the major AMB suppliers.

Eliminating multiple and repeat adoptions by the end-users from this data yields Figure 3, a more modest view of the penetration of AMB technology because these are first adoptions only. Although a prediction of the total number of applications would certainly be of interest, no mathematical model would be capable of this type of forecasting with certainty.

Sustained adoptions of AMB technology did not occur until the mid 1990s with the advent of the second technology generation that addressed the teething problems that had caused the early decline in new adoptions of the first generation technology. The second generation technology introduced several significant improvements in AMB controllers. Most importantly, digital electronics were introduced enabling more flexible and faster implementation of control algorithms.

The control algorithms were, in turn, derived from newly developed fully integrated rotor-bearing system models that allowed a complete definition of system response and stability. In addition, higher (by more than twofold) output power rating of the amplifiers used to drive current to the AMB coils were also used for the first time.

These technology features allowed the robust control of fully levitated machine trains. Evolution of electrical designs coupled with improved thermal management assured higher reliability comparable or superior to oil lubricated systems. The digital technology employed with the electronics assured shorter commissioning of new machines while enabling remote communications that enhanced the operability of the system. In turn, the latter allowed reductions in operating and maintenance personnel to be consid-

ered, thereby lowering operating costs.

In addition to the above, designs for direct immersion of the AMBs and auxiliary bearings in the process fluid were introduced thereby reducing bearing spans, eliminating seals and realizing much simpler and more reliable designs. This capability is especially significant in those cases where contamination and corrosion are an issue.

Lastly, advanced auxiliary bearing designs were introduced that not only extended the service life before replacement but had a much greater capability for protection of machine internals under arduous field conditions. These new features and capabilities allowed resurgence in the adoption of AMB technology by more end-users as shown in the right side of Figure 3.

Reviewing Figure 3, it can be seen that the data comprises a fairly smooth curve except for the "kink" in the mid 1990s at the end of life for the first generation systems and before the second generation designs were adopted.

Using math models

The Bass mathematical model has been applied to identify the rate at which first time buyers make single purchases. Variations of this model have been developed to address different circumstances including repeat sales and multiple unit sales. The Bass model and most of its variations consider that new technologies diffuse into the marketplace by mass media and a word-of-mouth effect as new adopters communicate their experiences both internally and externally. These communications serve to encourage more adoptions internally as well as to build "pressure" on other potential users to adopt to take advantage of technology attributes and remain competitive with adopters.

Using Monte Carlo simulation to resolve intrinsic uncertainties, the Bass Diffusion Model can be applied to the diffusion of active magnetic bearing technology into the realm of oil lubricated bearings in large turbomachinery to describe the historical record, and to show at what rate the current second generation of this technology will be adopted with first purchases by new adopters. Despite the impressive total number of new AMB applications to compressors, the Bass model indicates a longer-than-typical time to adoption by new end-users, thus suggesting an inefficiency in the word-of-mouth communications mechanism believed by Bass to be fundamental to the sustained adoption of new technologies. As the lag in these communications is erased, the adoption rate will revert to the typical industrial trend and continue its substitution for oil lubricated bearing technology in large compressors.

The discussion about generational adoption also brings into question the next generation of AMB designs and how that will impact the adoption rate. Generation three will feature self tuning, advanced adaptive vibration control, advanced self diagnostics (expert systems), and transient overload capability for the auxiliary bearings. Some of these features have already been demonstrated by certain AMB suppliers (see Waukesha product announcement on p.37). Rapid adoption should occur because of the carryover effect from the second generation. TI

Author

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