

APPLICATION OF SYSTEMATIC INNOVATION TREND PREDICTION TOOLS TO THE DESIGN OF FUTURE BEARING AND LUBRICATION SYSTEMS

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Abstract

The paper describes how an evolved and expanded version of the Theory of Inventive Problem Solving, TRIZ has been used to predict the future evolution of bearing and lubrication systems. The paper describes some of the predictable trends of technical system evolution uncovered after over 1500 person years of study of the global patent database, and how they have been applied to identify the untapped evolutionary potential of today's state of the art designs. The paper describes the directions predicted by the trends, the resulting benefits expected to be made available to users, and the research and development requirements that will need to put in place to make the benefits a practical reality.

Introduction

The Russian inventive problem solving method, TRIZ, is built on over 1500 person years of research and the systematic study of over 2 million of the world's most successful patents (1, 2). The method thus encapsulates the best practices of the world's best inventive minds and, by using the patent database as its source material, strips away all barriers between different industry sectors. One of the key findings of the research shows that different industries have historically done a lot of wheel re-inventing, and that good ideas travel relatively slowly between different sectors.

The research has also demonstrated that there are a number of generic technology evolution trends that determine the evolution of all technical systems. These trends describe evolution towards:-

- systems with increasing benefits and decreasing cost and harm
- increased dynamization within systems
- increased system segmentation
- increased space segmentation
- increased surface segmentation
- increased controllability
- increased complexity followed by reduced complexity
- use of all available physical dimensions within a system
- decreased number of energy conversions
- increased rhythm co-ordination
- increased action co-ordination

In each case, researchers have identified a number of generic evolution steps up to and including a 'final' level of evolutionary potential.

The trends and the 'evolutionary potential' concept act together as powerful guides to help determine the future development opportunities and limits for a wide variety of technical and non-technical systems.

The paper describes an updated version of the classic TRIZ trends and the results of a series of short studies to apply them to the design of bearing and lubrication systems for hydraulic applications.

The paper begins with a section describing the concept of evolutionary potential. The next section integrates descriptions of the generic technology evolution trends with their application to predicting the future evolution of bearing systems. This section ends with the inclusion of the evolutionary potential diagram for bearing systems. Third and fourth sections then apply the same trends to draw the equivalent evolutionary potential diagrams for lubrication and filtration systems respectively. A short final section speculates on the research and intellectual property implications of the capabilities offered by the evolved TRIZ trends.

Ideality

One of the main pillars in the TRIZ philosophy is the concept of systems evolving in the direction of increasing ideality (defined as the sum of the good things in a system divided by the sum of the bad things). The concept also includes the idea of an 'ideal final result (IFR)' – defined as the evolutionary limit of a system in which all of the good things are delivered, and all of the bad things have disappeared. While this might sound somewhat fanciful on many levels, there are nevertheless many cases where such an IFR has been realised; this is particularly so when considering components within a bigger system.

The idea of a bearing system in which the user achieves the useful function of the bearing without the bearing actually existing is one of those examples where the IFR is probably some distance into the future. An important thought when comparing the exercise here with the idea of an IFR bearing is that here we start with an existing system and use the trends to project its evolutionary limits, rather than adopting the usual IFR practice of starting from IFR and working backwards. Thus it will be seen that in going forwards from the known it may well become apparent that the evolutionary limits of a given design style – in the first instance 'rolling element contact bearing – will fall short of the IFR. We illustrate this concept in Figure 1.

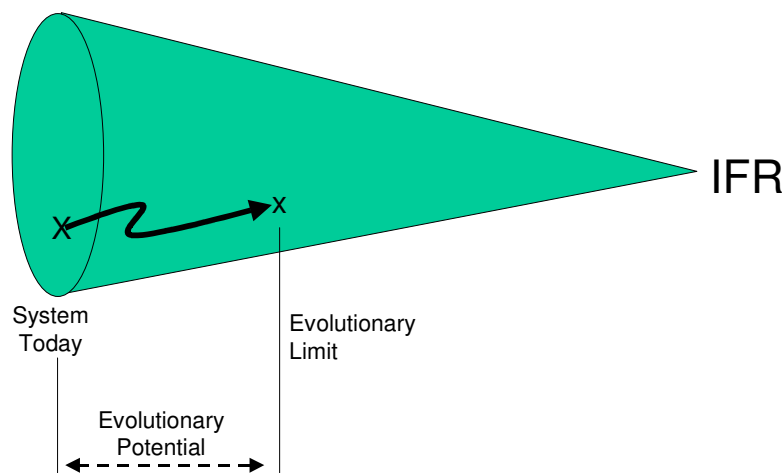


Figure 1: Ideal Final Result and 'Evolutionary Limit' Concepts

This 'starting from today and projecting forwards' philosophy is justified on the grounds that many organisations do not have the freedom to simply shift to another – potentially very different – design philosophy. Nevertheless, before travelling down this route, it is worth looking at the TRIZ 'object segmentation' trend as a way of illustrating one of the likely routes towards the ideal final result bearing system.

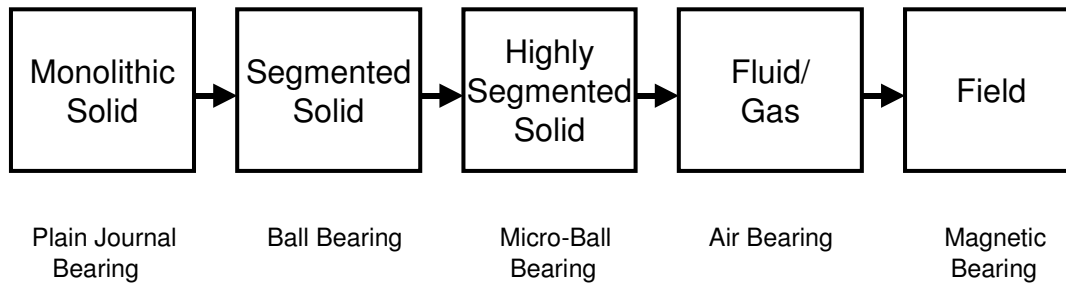


Figure 2: Object Segmentation Trend Applied To Bearing Design

The object segmentation trend is consistent with the overall evolutionary theme of 'doing more with less'. In terms of bearing design the trend implies replacement of mechanical bearing elements with first fluids and air and ultimately use of fields. Magnetic bearings, of course have been around for some time in specialised applications. Undoubtedly the widespread use of magnetic bearings will demand the solution of a number of problems to be found on current designs (primarily at the moment 'touchdown'), but the trend very much suggests that the benefits to be gained through successful development of magnetic or other field-based bearings will ultimately make them very attractive to customers in an ever widening arena of applications.

It might also be noted at this point that the road to ideality at the component level must necessarily also include consideration of the components and systems around the bearing. If the ideal final result bearing is 'delivering the function of the bearing, without the bearing being present'; it will be one of the other components around the bearing that will ultimately take over its function. In TRIZ terms, functions migrate to higher level systems, and hence lower level components are 'trimmed' from the system. What this might mean in the context of bearing design is beyond the scope of this paper. In the case of filter design – where that IFR position appears rather closer – the filter as we know it is likely to be eliminated and its function will be transferred to the pump or other rotating system that might provide the resources necessary to deliver a more effective 'filter' function. Ultimately, of course, it may be seen that the need for the function 'filter' disappears altogether if hydraulic systems become able to survive by protecting themselves from contaminant debris.

Evolutionary Potential

Putting the IFR concept on one side, the remaining bulk of this paper looks at the exemplar hydraulic system components from the rather more pragmatic standpoint of starting from a current design, observing where it appears relative to the TRIZ predicted technology evolution trends, and consequently examining how much closer to ideality it has the ability to evolve. A component or system that has evolved all the way along each of the TRIZ trend may be said to have reached its evolutionary limit. Any unexploited evolution steps represent 'evolutionary potential' (3). The evolutionary potential plot illustrated in Figure 3 is used as a way of describing how far along each of the TRIZ trends

a given system has evolved. Each spoke in the plot represents one of the TRIZ trends relevant to the given component. The outside perimeter of the plot represents evolutionary limit, and the shaded area represents how far along each trend the current system has evolved. Thus the area difference between shaded area and perimeter is a measure of evolutionary potential.

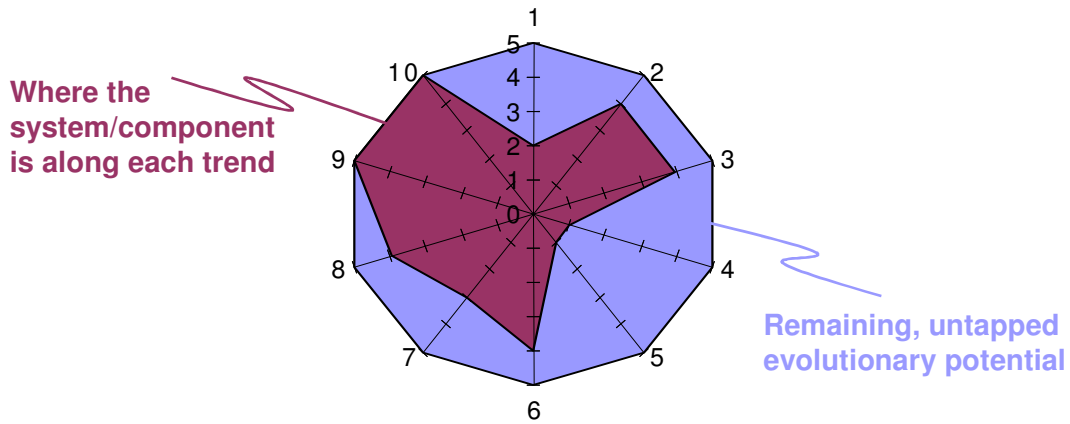


Figure 3: Evolutionary Potential Radar Plot

The construction of an actual evolutionary potential plot is best observed through consideration of a real example. We start below with a state of the art rolling contact element bearing:

Bearing Systems

The start point for defining the evolutionary potential of hydraulic system bearings has been to select a recent granted patent. US patent 6,296,395, granted in October 2001 to FAG in Germany has been chosen as a suitable starting point. The self-aligning bearing concept is illustrated in Figure 4 below.

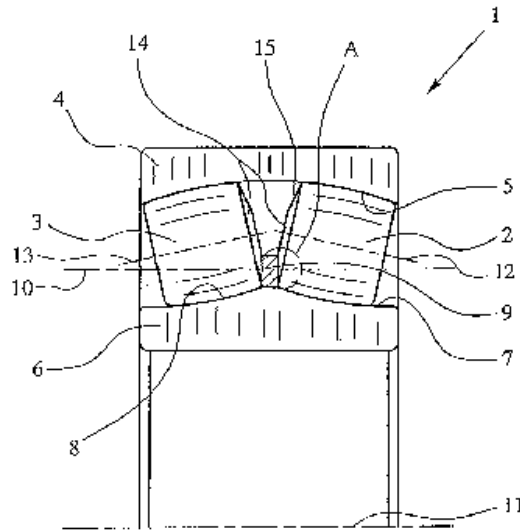


Figure 4: Exemplar State Of The Art Bearing System

The task now is to compare the bearing design with each of the TRIZ trends in order to find a point along the trend that best describes the current evolutionary state of the design.

By way of example, Figure 5 describes the TRIZ trend known as 'space segmentation'. The trend shows a progression observed in other systems from solid to hollow to multi-hollow to capillary to active designs. As in all the other trends being presented, TRIZ depicts an evolutionary progression from left to right across each trend, in which benefits increase as a design travels further to the right.

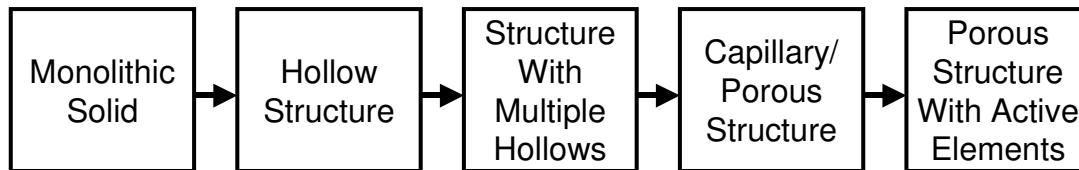


Figure 5: Space Segmentation Trend

For the US6,296,395 design, it may thus be observed that the design uses solid roller structures. As such it has evolved along only one out of the possible five evolution stages (NB obviously the idea of hollow ball construction predicted by the trend has been achieved elsewhere and hence the equivalent evolutionary potential plot for that system would denote two out of the possible five stages of evolution). The space segmentation spoke on the radar plot the shaded area boundary for the chosen invention however will be drawn one-fifth of the way along a spoke with five graduation marks.

In terms of the current design, the task of the designer is now to work out what benefits may be accrued by tapping into the unexploited evolutionary potential. In other words, how would a hollow or multi-hollow or capillary structure offer benefits over the current hollow design? Possible examples might include increased strength/weight ratio, increased lubrication carrying capability and so on. The identification of such benefits often results in the opportunity to generate significant new intellectual property. For obvious reasons, this paper does not seek to travel in that direction.

Instead, the process of comparing the exemplar design to the TRIZ trends continues with the geometric evolution trend shown in Figure 6.

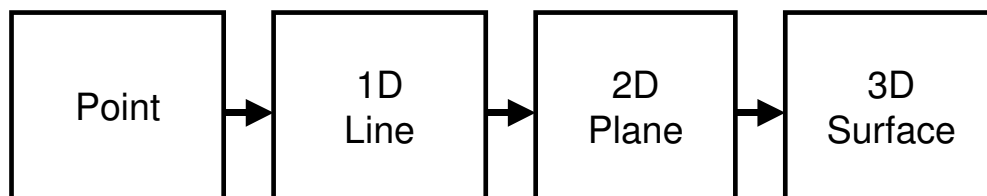


Figure 6: Geometric Evolution Trend

This is perhaps one of the more obvious trends; one in which benefits increase as a design exploits all of the available degrees of freedom. This is a particularly important trend in the context of many manufactured products; especially in examining the potential for evolution from the 2D to fully 3D stage, where, historically, it has been easier to manufacture things using 2D machining operations and consequently one of the available degrees of freedom has not been exploited. The increasing availability of machining capabilities where the difference in cost between 2D and 3D is zero means that the untapped benefits to be had by utilising the third dimension can be accrued without increased cost (i.e. the cost-benefit contradiction has been resolved by better manufacturing technology).

In the case of the exemplar bearing, although the roller profile has taken advantage of some degree of three-dimensionality, the invention disclosure talks specifically about symmetrical designs and hence in TRIZ trend terms the third dimension has not been fully exploited. Several other areas where the third dimension has not been fully used may be seen – for example the profile of the inner and outer races, and the end planes of the bearing – and as such, the evolutionary potential plot should show that only three out of the four evolution stages have been exploited.

A close relative of the space segmentation and geometric evolution trends is the surface segmentation trend illustrated in Figure 7. This trend defines increasing benefits to be gained by evolving smooth surfaces into 2D and 3D surfaces. As with the space segmentation trend, the bearing under evaluation does not make use of any of the predicted evolutionary steps beyond the first; it thus has significant untapped surface segmentation evolutionary potential.

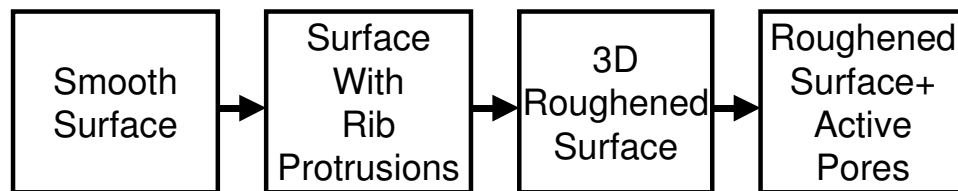


Figure 7: Surface Segmentation Trend

The controllability trend illustrated in Figure 8 is highly relevant in a bearing design context. The trend is specifically interesting here in terms of the use or otherwise of feedback in a system. It suggests the questions ‘does the bearing design contain feedback, and what might the potential benefits of incorporating feedback be?’ In answer to the first question, the exemplar bearing (and most other bearing designs) do not feature any form of feedback. Possible advantages of integrating some form of feedback into the system might then include various options for monitoring the health of the bearing, for measuring loads, or for allowing optimisation of the operation of the bearing based on varying operating conditions.

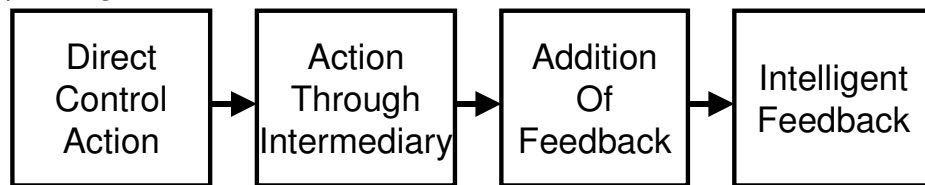


Figure 8: Controllability Trend

While all of these potential benefits are speculative, it is clear that the 6,296,395 bearing design – like the majority of other mechanical designs has significant untapped evolutionary potential in this area. Most likely this is due to some of the difficulties and likely complexity of achieving feedback in mechanical systems (TRIZ would encourage designers to identify existing resources within the system to help deliver the required function without complicating the system). It may be observed that magnetic or other ‘field-based’ bearings do not carry such difficulties – and in fact ‘controllability’ is one of the main benefits offered by evolution to such bearing design paradigms.

Lack of space dictates the absence of the details of the evolutionary potential analysis for the other trends in the TRIZ set. Instead, Figure 9 illustrates the end result of the comparisons between the other relevant TRIZ trends and the 6,296,395 design. The figure

thus acts as an example of the sort of analysis that can and increasingly is being conducted for other systems. For the design under evaluation, the plot clearly shows there to be considerable amounts of untapped potential in the design, and therefore that there are consequently significant improvements that we be developed.

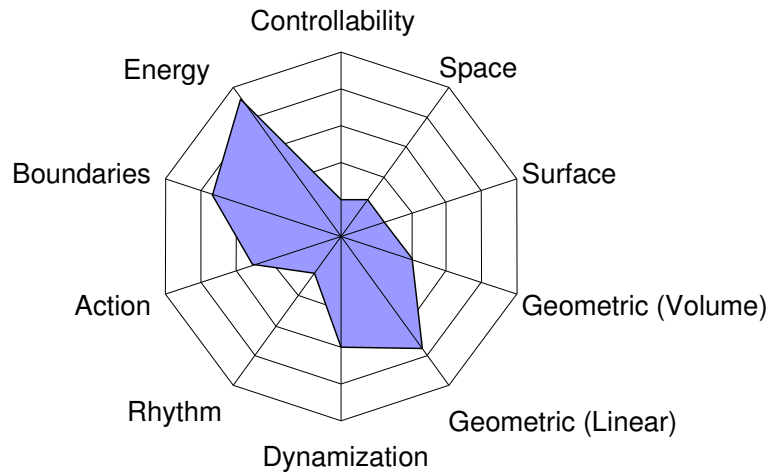


Figure 9: Bearing System Evolutionary Potential Radar Plot

It should be noted at this point that while this plot has been drawn for the bearing as a whole, it is often the case that the analysis is conducted at the level of individual components in order to define a series of evolutionary plots. Such plot families offer significant potential in terms of identifying areas to focus R&D efforts – for example there will be little point in devoting resources to developing a component with little remaining evolutionary potential when there are other components which are still at the un-evolved stages of several of the TRIZ trends.

Lubrication Systems

Space considerations again dictate that a complete analysis for a typical lubrication system cannot be detailed step-by-step. Instead, Figure 10 reproduces a summary evolutionary potential radar plot for the illustrated exemplar lubrication system – a Finnish patent from April 2001 describing a flow control arrangement in a generic circulation lubrication system.

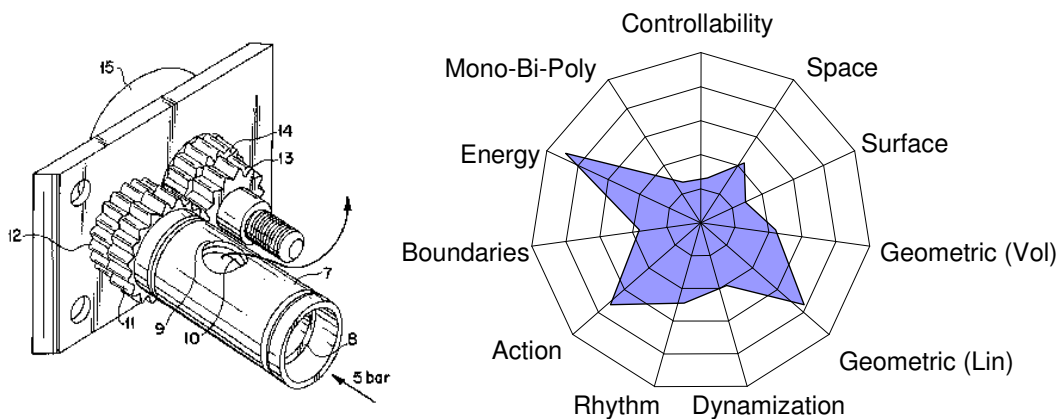


Figure 10: US patent 6,217,004 Lubrication System Evolutionary Potential Radar Plot

As with the preceding bearing example, the point of the figure is to illustrate the principles of the evolutionary potential concept and to examine the evolutionary state of a specific design. As with the bearing example, Figure 10 suggests that yet another state of the art design still offers the potential for significant evolution, and thus greater customer (and for that matter, manufacturer) benefit.

Filtration Systems

Figure 11 repeats the message of significant untapped potential for a typical hydraulic system barrier filter design.

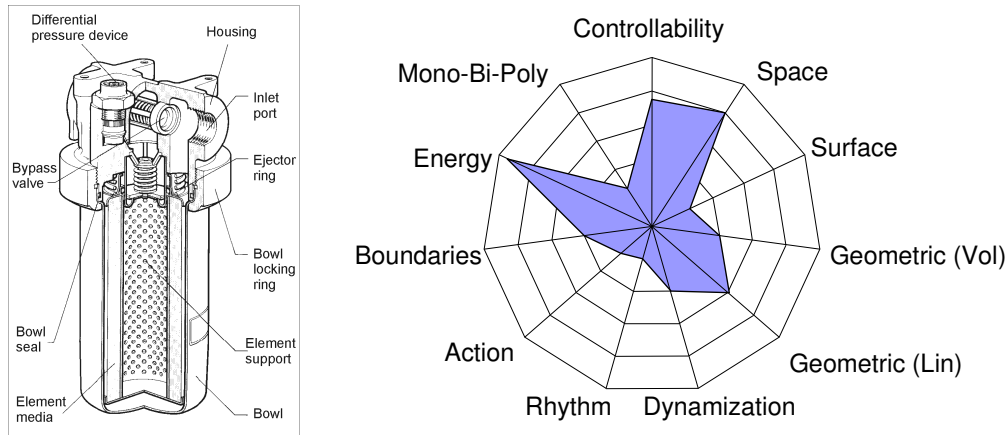


Figure 11: Filtration System Evolutionary Potential Radar Plot

Based on work elsewhere (4) examining alternative means of delivering the function (function and functionality represents another vital aspect of TRIZ) ‘separate contaminants’, it remains to be seen whether filter manufacturers will be able to develop and exploit this potential for barriers before an alternative system – one much more likely to achieve a true Ideal Final Result of achieve the function without the system – emerges to displace the barrier. This, of course is the difference between traditional ‘improve the current’ and ideality based ‘start from IFR and work back’ thinking.

Conclusions and Future Implications

The study concludes that both areas, although perhaps thought of as ‘mature’ technologies, have considerable levels of untapped evolutionary potential remaining, and that there are consequently significant opportunities for development of both large quantities of intellectual property and improved performance benefits to customers.

The Ideal Final Result strategy contained within TRIZ, however, highlights a possible danger. Most companies are happier – and local operating constraints often dictate – working left-to-right, starting with an existing system and evolving it through ‘continuous improvement. This is fine until someone – usually someone from outside the industry based on historical analysis (5) – works out that the road to ideality is better travelled starting from IFR and working back. The evolutionary limits of an existing system may be some considerable distance away from the IFR for that system. While the evolutionary potential concept is important in terms of improving existing products, it is no substitute for an IFR start position in the large majority of instances.

TRIZ also shows that sub-systems and components like bearings, filters, etc often achieve ideality (i.e. delivering the function without the system existing) by having something else higher up the overall system hierarchy perform the function. This is usually the direction from which the main threat to a sub-system comes. Organisations need to obtain a much more holistic view of the places of their products, processes and services in the bigger scheme of things if they are to have a chance of countering the threats from other, higher level systems.

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