# NEW PARADIGMS FOR IMPROVED RELIABILITY, ZERO-LEAKAGE HYDRAULIC SYSTEM DESIGN

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## ABSTRACT

The paper demonstrates how the Russian inventive problem solving method, TRIZ, can and has been used to design fluid power components and systems in which the 'inherent' trade-offs have been eliminated and new design paradigms have been created. The paper also shows how new paradigms can be achieved through a better sharing of knowledge between industry sectors. New paradigms mean better hydraulic system designs with greater reliability, reduced leakage, and longer, more predictable life. A number of case study examples are presented, including some of the conceptual studies taking place at the University of Bath looking at novel rotating and static seal designs.

## INTRODUCTION

Designers traditionally find themselves trying to perform a delicate balancing act between conflicting design parameters; weight versus strength, speed versus life, efficiency versus complexity, or efficiency versus cost, to name but a few common trade-off scenarios. In each case, as the designer tries to improve one parameter, the other tends to get worse. Higher shaft speeds mean shorter bearing life, close tolerance gears in a gear pump mean greater pumping efficiency but higher manufacture cost, and so on.

This type of design trade-off is also inherent to the design of seals and couplings: reduction of system pressures means lower leakage but bulkier systems; higher coupling fastening- loads mean better sealing but impaired reliability; increased coupling sophistication means better sealing but increased cost, etc, etc. The fact that leakage continues to be one of the biggest sources of hydraulic system problem – it is estimated, for example, that around 300 million litres of hydraulic oil are 'lost' in Europe each year – tends to suggest that designers are not adequately addressing the relevant design issues.

Unlike traditional design strategies, the Russian inventive problem solving method, TRIZ, (Reference 1,2) encourages designers to eliminate design compromises and trade-offs rather than accommodate them. Through 1500 person years of research and a comprehensive analysis of over 3 million of the world's patents, TRIZ encapsulates the best compromise-eliminating practices of the world's inventive minds.

TRIZ contains many problem solving tools and techniques. The paper will concentrate on just a few, demonstrating how they are being applied to develop new design paradigms associated with fluid power sealing requirements.

## FLANGE JOINT

The bolted flange joint is a very common engineering structure. The traditional approach taken in the design of such flange joints, is to balance between the many conflicting parameters present in the basic design concept. Although the designer may not always be directly conscious of the conflicts, it is possible to plot each one graphically in a manner similar to that shown in Figure 1. A typical design conflict, then, between two parameters A and B is such that as the designer tries to improve one, the other tends to get worse, and vice versa. The characteristic line relating the two parameters can be seen as a line of constant design capability.

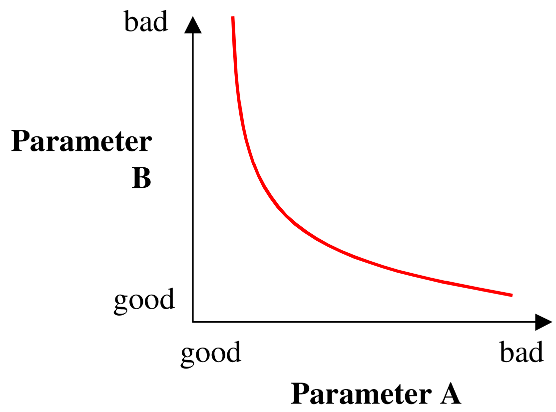


**Figure 1: Graphical Representation of a Typical Design Conflict**

With respect to a conventional flange joint design, several such conflict graphs may be depicted. For example, there are well-established design rules defining the number of bolts required around the joint to provide an adequate seal. The conflict here exists between the number of bolts used and the leakage performance of the flange. The task of the designer is then traditionally to find a balance between the two conflicting parameters. This process is illustrated in Figure 2.

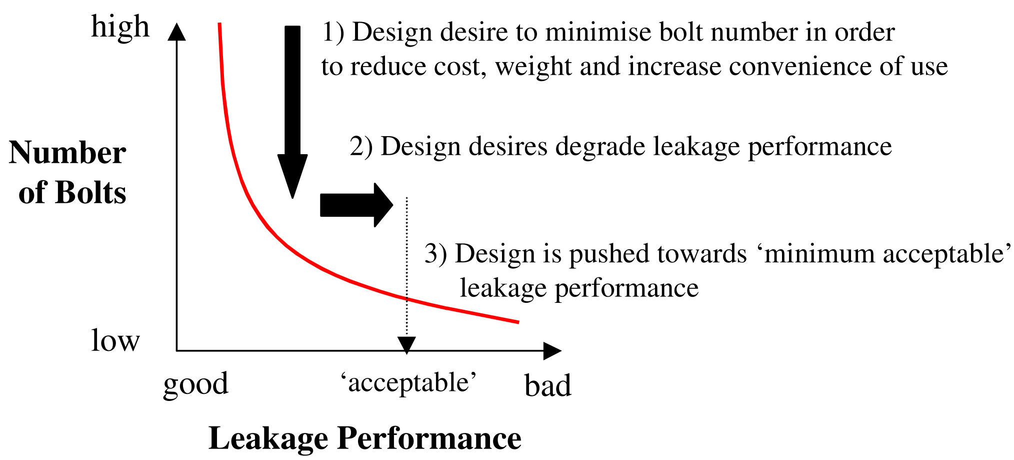


**Figure 2: Typical Flange Joint Design Trade-Off Process**

The graph perhaps also begins to explain why so many flange joints leak. This is particularly so when aspects like little the often poorly understood degradation of the flange performance over time are taken into account. I.e. what starts out as 'acceptable' sealing performance when the flange is new, turns into 'unacceptable' performance after the ravages of time and customer usage.

TRIZ encourages designers to identify and then seek to eliminate the sorts of conflict illustrated in Figure 2. The method has captured a generic problem solving framework through which a designer is able to map his or her own particular design conflict onto similar ones in which inventors have successfully overcome – i.e. 'eliminated' – the design conflict.

In the case of the flange joint design, Reference 3 describes how TRIZ could be used to break out of the traditional design trade-odd scenario to produce the paradigm-shifting design solution illustrated in Figure 3.

This design enables designers to achieve the same sealing performance as a conventional parallel-faced flange design with typically half the number of bolts.

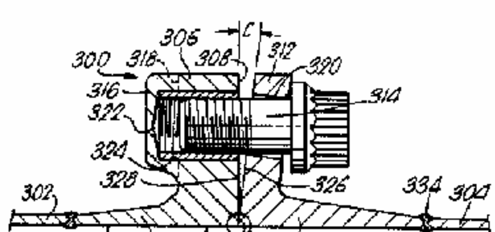

**Figure 3: US Patent: 5230540, 'Fluid-Tight Joint With Inclined Flange Face**

In terms of the original, Figure 1, conflict representation, by simply introducing a small angle onto one of the flange faces, the designer has drawn a new characteristic relationship between the parameters – Figure 4.

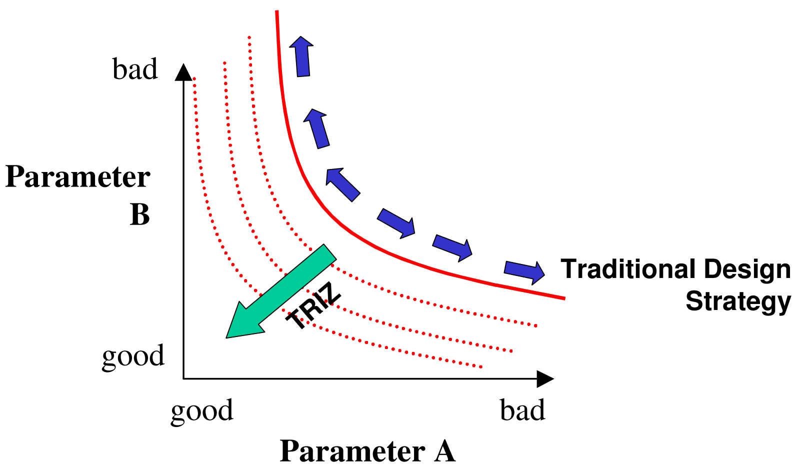


**Figure 4: Difference Between TRIZ and Traditional Design Approaches**

This figure graphically illustrates the key difference between the TRIZ and traditional 'design-is-a-trade-off' design approaches. As shown in the figure, the TRIZ process is commonly deployed in a manner where the design paradigm is systematically changed by successive application of the method to the design of the flange joint (Reference 4) until a point at some time in the future when the conflict may actually become 'eliminated' in a literal sense.

(Another example of a fluid power industry used system improved through TRIZ contradiction elimination methods is the heat exchanger case study described in Reference 5.)

## TRANSITIONING THE PARADIGM SHIFT TO OTHER AREAS

The angled flange joint design solution shown above is certainly not a new one, and was known about in certain industries long before the gas-turbine industry re-invented it for themselves in the Figure 3 design.

The point here is that 'good' design solutions have a very strong tendency to travel only very slowly between different industry sectors.

This is a phenomenon long recognised by the Russian researchers who constructed the TRIZ methodology. They have sought to overcome the problem through a combination of capture of inventive ideas in a truly generically applicable sense, and a recognition of the need to find a way of classifying these 'good' design solutions in a manner which makes them accessible to other designers in whatever industry sector.

It is often the case currently that these good solutions travel badly even within their existing industry sectors. An example of this – and also incidentally an example of the Figure 4 idea of successive design paradigm shift – is the conceptual V-Band clamp based design solution derived at Bath and illustrated in Figure 5.

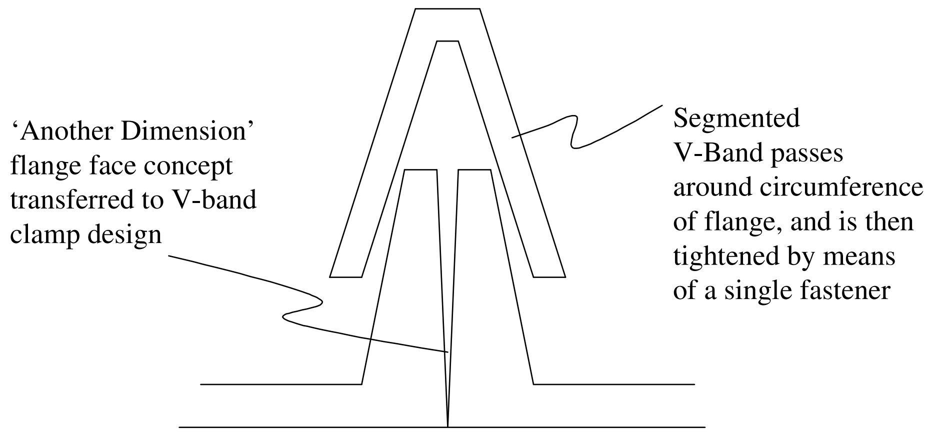


**Figure 5: Possible Application of Inclined Flange Face Concept to Other Design Solutions**

Here, the design achieves a better flange joint which uses only one bolt. It is also perhaps worth noting that there is no existing patent which covers this solution.

The angled-face/reduced contact area concept has also thus far failed to travel to other areas within and around the fluid power industry, despite the fact that there is no logical reason why it shouldn't. Thought about in this way, there is no reason why the concept couldn't similarly be deployed to significant beneficial effect in a whole host of fluid power industry applications from quick-release couplings to valve-block seals to hydraulic motor casings to actuator endcap designs… and so on.

## KNOWLEDGE TRANSFER

The problem of poor knowledge transfer between subject areas and industry sectors is illustrated in Figure 6.

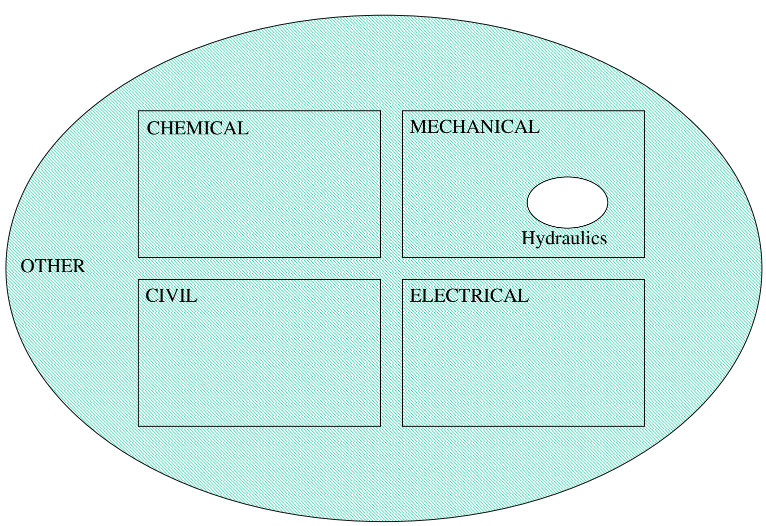


**Figure 6: Typical Fluid Power Industry Design Solution Search Space**

The figure suggests that a designer working in the fluid power industry is highly unlikely to look outside his or her industry to find problem solutions. The phenomenon is understandable from a number of perspectives, not least of which is the fact that a good designer will often have trained and practised for a considerable number of years in a particular discipline.

TRIZ calls this propensity to look for design solutions within the realms of our known experience 'psychological inertia' (Reference 6).

The flange joint example shows how TRIZ helps to overcome psychological inertia through a generic contradiction-eliminating problem solving framework. A second method is the more direct approach of expressing existing solutions in a form accessible to others. An alphabetic listing (for example) of all of the world's good design concepts and solutions would probably be of very limited value; adequate if the designer was looking for other 'flange' designs, but wholly inadequate if the search was required to be more broad.

The principle, then, upon which TRIZ makes good designs accessible to others in whatever industry they might be, is to classify the solutions in terms of their **function**. Thought about in this manner, the designer is no longer looking for a 'flange' – a specific solution – but is looking for a 'breakable joint' – i.e. a generic function.

Several such functionally-classified knowledge databases now exist. Probably the best of these databases is the one to be found in the Invention Machine TechOptimizer® software (Reference 7). The database found in the latest version of the software contains over 6000 physical, chemical and mathematical effects, and engineering design solutions, and by the end of the year will probably contain over 7500.

**ROTATING SEALS**

By way of demonstration of the classification of conceptual design solutions by their function, we might examine a case in which a designer is trying to achieve an effective seal between a rotating shaft and a stationary support structure.

Traditional solutions to this 'rotating seal' functional requirement within the fluid power industry predominantly comprise of labyrinth, o-ring, brush, or designs containing a combination of these types. Whilst undoubtedly rugged (and cheap), these design solutions also help to explain why so many hydraulic systems suffer from leakage problems.

TRIZ encourages to look beyond the current industry design conventions, and to establish whether other industry sectors have found other, better ways of achieving the 'rotating seal' function. One such solution is illustrated in Figure 7.

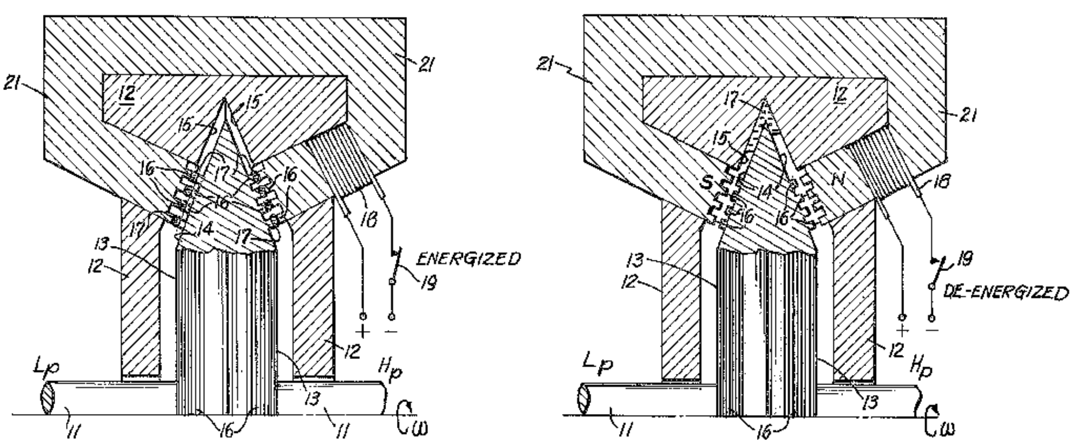


**Figure 7: US Patent 4,455,026 Magnetic/Centrifugal Seal**

This design solution – originally conceived for use in the aerospace sector – makes effective use of a ferro-magnetic fluid to provided a seal during low pressure differential, low rotational speed operation, which then turns into a powerful centrifugal seal as duty increases.

Of course, there will need to be certain modifications to such designs to accommodate the specific boundary conditions of the adopting industry sector, but there is no doubt that conceptually the above magnetic seal offers a highly rugged, affordable (particularly with a non-switched magnet), low friction, zero-fluid-loss solution to a variety of fluid power system design problems.

Similarly, other rotating seal solutions from other industries include the design – taken from the laboratory equipment high-vacuum sector this time – which may be appropriate in some form in fluid power based applications.

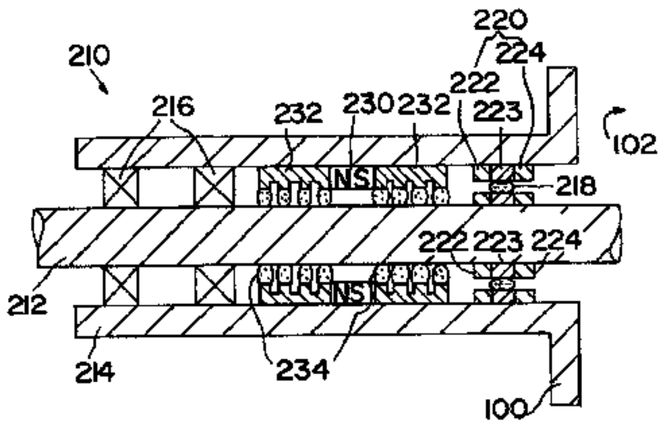


**Figure 8: US Patent 5,799,951 Liquid Metal Rotating Seal**

## CONCLUSIONS

1) Hydraulic system leakage is becoming progressively less acceptable to customers due to increasing environmental awareness and increasing expectations with respect to system reliability, maintenance-free operation and durability demands.
2) Current design methods do not appear to offer adequate answers. The existing seal-related design paradigms are approaching the limits of their capability. New paradigms are required if significantly better solutions are to be achieved.
3) Tools contained in the TRIZ inventive problem solving methodology – particularly those associated with contradiction 'elimination' – offer significant potential for shifting design paradigms to allow the realisation of significantly more reliable, zero-leakage hydraulic systems.
4) Like many other industry sectors, the fluid power industry is guilty of failing to take maximum advantage of the good design solutions obtained in other sectors, despite the fact that the functions being sought – e.g. 'seal' – are commonly very similar.
5) The TRIZ methodology, coupled with emerging function based 'knowledge management' capabilities, provides a basis upon which the good solutions from other industries can be made readily accessible to fluid power industry companies.
6) Novel static and rotating seal design concepts, building on paradigm-shifting TRIZ and knowledge transfer principles, have been suggested.

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