

DESIGN WITHOUT COMPROMISE: A New Perspective On Fluid Power System Component Design

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Abstract

Design without compromise is about eliminating the design trade-offs most non-Russian engineers normally take for granted. The Russian inventive problem solving method, TRIZ provides engineers with an array of tools and techniques constructed from the global patent database which enable such trade-offs to be eliminated.

The paper examines some of the main TRIZ tools and seeks to demonstrate how they may be applied across the fluid power industry to achieve elegant and novel solutions to seemingly intractable problems.

1.0 Introduction

Most real world organisations are caught in a constant battle to produce ever more and ever better products with ever fewer resources.

Fewer engineers with more to do is a combination which usually leads to a strong focus on fire-fighting today's problems with today's tools and techniques. The 'quick-fix' is very much the order of the day.

All too often, the 'quick fix' turns out to be no fix at all. At least not in terms of overall business performance. The reason for this is very simply that by fixing the symptoms of a problem – rather than the root causes – we tend to generate a new solution which is fundamentally more expensive to produce than the old one. Adding a palliative is very much easier than finding a root cause. Especially when time is short.

Very few engineers have an appreciation of enormity of their responsibilities regarding overall business performance. Very few engineers appreciate that by the time they've even sketched a concept design, they have probably committed something like 80% of the manufacture cost of the product and quite likely a similar percentage of the product's total life-cycle cost. And this at a cost – the cost of the time spent by the designer – of something like 1 or 2% of the total.

This spend/commitment discrepancy (Figure 1) vividly says businesses should allow engineers to spend more time thinking before the rest of the organisation starts any doing.

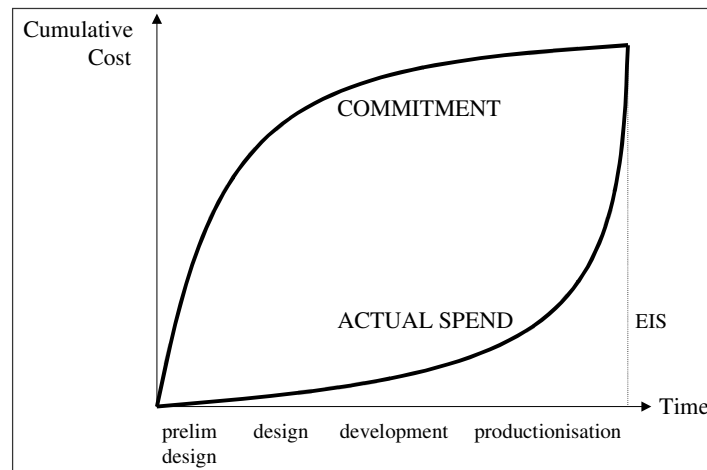


Figure 1: The Spend/Commitment Discrepancy

Russian naval officer and patent engineer Genrich Altshuller had the idea that all of the examples of ‘good’ design practice – the designs which succeeded in achieving maximum functional benefit from minimum use of resource – followed common solution strategies. He also felt that these strategies could be systemised. And so Teorija Rezhenija Inzhenernyh Zadach (TRIZ) – or, in English, ‘Theory of Inventive Problem Solving’, was born.

TRIZ research began in 1946 with Genrich Altshuller’s hypothesis that there are universal principles of invention that are the basis for creative, technology advancing, innovations (1). Altshuller believed that if these principles could be identified and codified, they could be taught to people; and thus could make the process of invention more predictable. TRIZ research has proceeded in several stages over the last 50 years, now accumulating over 1500 man-years of scientific study and going far beyond Altshuller’s initial hypothesis. The three primary findings of the research are:

- 1. Problems and solutions were repeated across industries and sciences**
- 2. Patterns of technical evolution were repeated across industries and sciences**
- 3. Significant innovations used scientific effects outside the field where they were developed**

Much of the practice of TRIZ consists of learning these repeating patterns of problems-solutions and patterns of technical evolution, and methods of using scientific effects, and applying the general TRIZ patterns to the specific situation that confronts the developer. Figure 2 describes this process graphically.

Altshuller’s work on problem classification and the discovery that there are only a very small number of Inventive Principles available to the engineer is already profoundly changing the systematic innovation picture. That there are only these small number of principles has, for example, meant their systemisation in software form has been relatively

easy. The emergence of a number of commercial packages built around TRIZ ideas (2,3) is therefore not surprising.

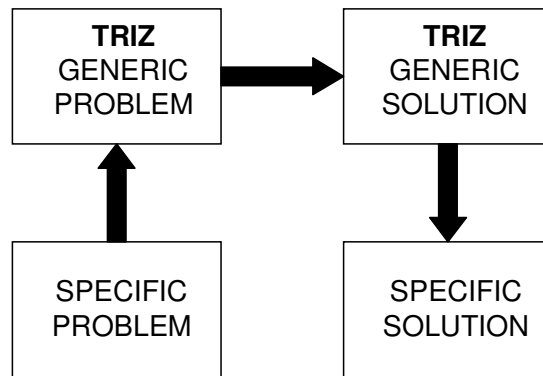


Figure 2: The General Model For TRIZ Problem Solving

This concept of identifying the contradictions in a design and correlating them to how other inventors have solved the same types of problem is but one element of what is now a much broader TRIZ methodology covering:-

- Trends of technology evolution classified in terms of generic function-based parameters.
- Classification of physical, chemical, and mathematical effects into a function-based database structure.
- The concept of ‘Ideal Final Result’; a means of first helping to define the problem to be solved and then a method for establishing the route towards the optimum (compromise-free) solution to that problem.
- A database of what Altshuller described as ‘Standard Inventive Solutions’ and a method – known as the Algorithm for Inventive Problem Solving (ARIZ) – through which inventors are able to classify and discover effective means of solving problems.

The paper examines the evolution trends, effects, Contradictions, Ideal Final Result and Standard Inventive Solutions parts of TRIZ from a fluid power industry perspective, and looks at how TRIZ is being applied at the University of Bath to shift a number of design paradigms surrounding seemingly intractable problems.

2.0 Case Study 1: Flanged Joint

In order to demonstrate some of the differences between the traditional design approach and the TRIZ approach, it is useful to look at the example of a flange joint design.

A flange joint is designed to carry a variety of loads and moments whilst simultaneously forming a satisfactory seal. Traditional logic says that if a flange is designed and tested and is found to leak, the way to rectify that leak is to do one of three things: 1) increase the bolt torque, 2) increase the number of bolts, or 3) add a gasket of some sort. Ninety-nine times out of a hundred, the ‘quick-fix’ solution to the leaking flange problem would be to do one of these things. In each case, however, although the immediate problem may have been fixed,

the designer has merely solved the problem at the expense of something else in the design. Increasing bolt torque has degraded life expectancy of the joint, increasing the number of bolts has increased the overall weight and maintenance time, and adding a gasket has increased assembly and maintenance cost, and decreased life. The designer has in effect done no more nor less than find a different point on the same trade-off characteristic.

In TRIZ terms, the designer has designed by compromise. Given the same leaking flange scenario, TRIZ gets the designer to examine the design from a compromise-free perspective. In this case, 'design without compromise' will have been achieved if a design with a large number of bolts (good seal) AND a small number of bolts (low weight) can be devised. Identification of this type of paradoxical contradiction statement is an important aspect of TRIZ.

The Contradiction Matrix (5) provides a potent means of connecting such statements to inventive ways in which other engineers have managed to solve similar generic types of physical contradiction.

Reference 6 details the process by which the flange joint problem may be solved without compromise. Needless to say, it is possible to design a better seal with fewer bolts. The answer is illustrated in Figure 3. Tests on this type of flange joint (7) have demonstrated that it is actually possible to halve the number of bolts relative to conventional design practice.

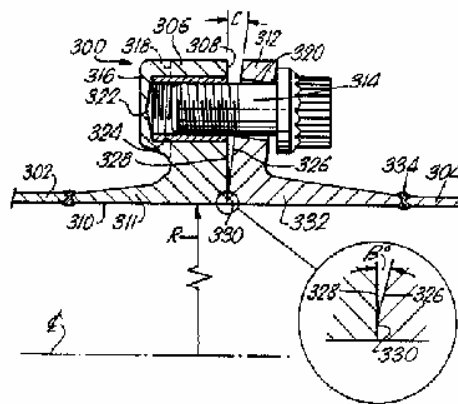


Figure 3: Fluid-Tight Joint With Inclined Flange Face, US Patent 5,230,540

The inclined flange face idea is one which may well be applicable to a number of fluid power industry related product designs beyond flange joints.

3.0 Case Study 2: Filters

The current state of the art of fluid power system filtration is the barrier type filter illustrated in Figure 4.

A common starting point in TRIZ thinking is to look at the compromises and trade-offs present in the state of the art. In the case of filtration systems, those trade-offs include:-

- | | |
|---|--|
| <p>* PHYSICAL SIZE</p> <ul style="list-style-type: none"> - contaminant holding capacity, - pressure loss versus weight | <p>* MESH SIZE</p> <ul style="list-style-type: none"> - circuit protection versus filter life |
|---|--|

* MEDIA TYPE

- cleanable versus disposable

* OPERATING PRESSURE

* BYPASS/NO-BYPASS

Recognition of the trade-offs is a very good first step towards removing them. Altshuller's trends of technology evolution provide one of the ways of determining how such trade-offs might be removed.

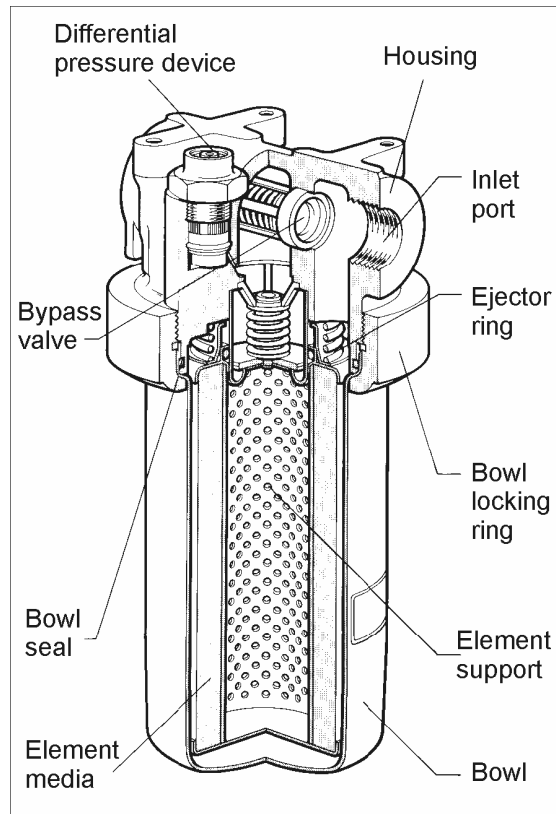


Figure 4: Typical Current Generation Filter Assembly

Strictly speaking not one of Altshuller's discoveries, but nevertheless consistent with all the trends he did discover is the universal trend towards increasing product 'ideality'. This idea was first discussed by Larry Miles (8). Miles defined 'ideality' or 'value' as:-

$$\text{Value} = \text{Benefits} / (\text{Costs} + \text{Penalties})$$

The 'law' of increasing product 'ideality' in the context of the fluid power system filter system says that future systems will evolve towards greater benefit (better circuit protection), lower cost (cost of filter, life-cycle cost of system into which filter is designed) and reduced operating penalties (lighter filters, reduced volume, better disposability, etc). None of these should appear particularly surprising.

Miles' ideas are commonly expressed in terms of the S-curves of product evolution. S-curves show trends of increasing ideality through successive generations of product evolution.

Altshuller's trends of evolution discoveries are based primarily on analysis of the global patent database and have thus concentrated on the physical manifestations distinguishing one product generation from another. Among a host of patterns of evolution spotted by Altshuller (1) is the example of 'trimming'.

The 'Trimming' evolution trend (Figure 5) says simply that products will evolve to contain progressively fewer components. Generally speaking, the reduction will eventually be achieved with no decrease in product functionality.

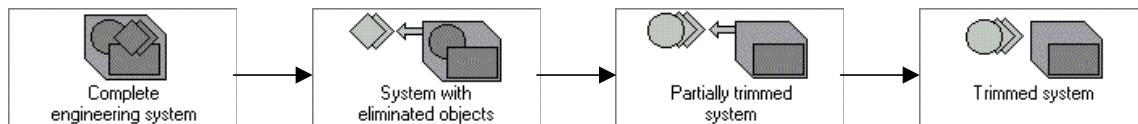


Figure 5: 'Trimming' Evolution Trend

Another trend potentially relevant to the design of filters is 'Surface Segmentation' (Figure 6):

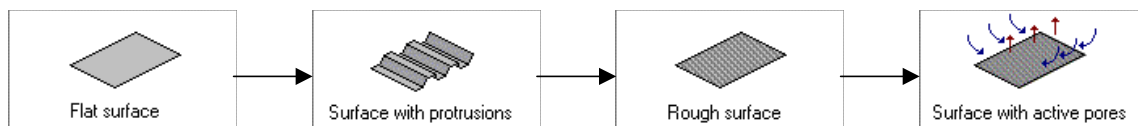


Figure 6: 'Surface Segmentation' Evolution Trend

Thinking now in terms of some of the current filtration system trade-offs and these example evolution trends, it becomes possible able to see how the latest generation 'core-less' filters have evolved.

Conventional disposable filters involve disposal of the filtration medium and the supporting structure (element support, bowl, etc). Disposal occurs because the filtration medium is filled with contaminant. The support structure around the medium, however, has much useful life left. The 'increasing value' and 'Trimming' trends suggest that the support structure should be made re-usable and only the filtration medium is disposed of. Which, indeed turns out to be exactly what happens in, for example, US patent 5,762,788 (Figure 7).

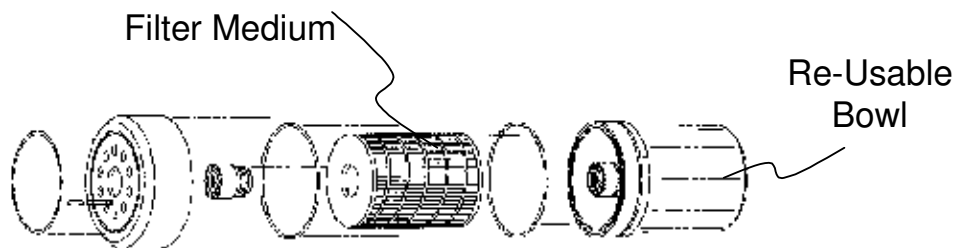


Figure 7: US Patent 5,762,788 'Fluid Filter Having Re-Usable Filter Housing and a Replaceable Coreless Filter Element'

The 'core-less' filter is indeed a useful - perhaps 'generational' - advance in filtration technology. It ought to be possible to employ the evolution trend patterns to project further advances beyond this core-less unit.

Altshuller, conceived the Ideal Final Result (IFR) philosophy as another means of assisting in the derivation of future technology advances. In effect, the IFR approach is a way of encouraging designers to look at the furthest evolution along the trend paths.

There are a number of ways in which the IFR of a product can be developed. One such means is to pass through the following sequence of questions:-

- 1) **What is the final aim?**
- 2) **What is the IDEAL FINAL RESULT?**
- 3) **What is the obstacle to this?**
- 4) **Why does this interfere?**
- 5) **Under what conditions would the interference disappear? (What resources are available to create these conditions?)**

In theory, passing through the questions successfully should lead to the required IFR solution - at least conceptually. In the case of the fluid power system filter, for example, the following answers may emerge:-

- 1) **What is the final aim?**
To remove contaminants from circuit
- 2) **What is the IDEAL FINAL RESULT?**
Contaminants remove themselves from the circuit (Figure 8)

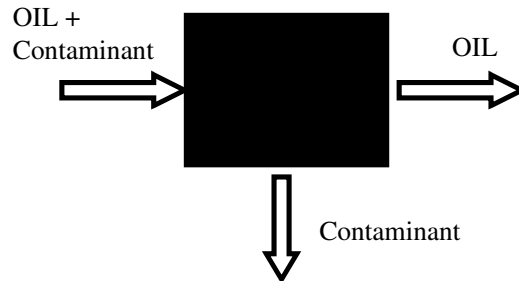


Figure 8: Filtration System 'Ideal Final Result'

- 3) **What is the obstacle to this?**
Contaminants follow the flow
- 4) **Why does this interfere?**
Since contaminants follow the flow, there is no means of removing them from the flow stream (except by using a barrier which stops contaminants but doesn't stop oil)
- 5) **Under what conditions would the interference disappear? (What resources are available to create these conditions?)**
contaminants able to move relative to flow
(contaminants have momentum, mass, shape, magnetic properties, etc)

Asked how many ways there might be to make a particulate contaminant ‘move’, evidence suggests engineers working in the particulate area might be able to name three or four.

Thinking more globally, other evidence suggests that the majority of engineers have working knowledge of perhaps 20-30 physical, chemical or mathematical effects, and maybe a passing knowledge of as many again.

The Invention Machine® software contains a massive database of such effects. One of the great beauties of what has been done with the database, however, is in following the lead provided by Altshuller to classify the database in terms of **function**. So, for example, the database collects all the known ways of making particles move under a single heading. At present the number of ways of moving particles contained in the database is 33:

* Gravity	* Laminar Flow	* Resonance
* Inertia	* Funnel Effect	* Vibration
* Acoustic Vibration	* Hyperboloid	* Turbulent Flow
* Birds Beak Effect	* Ion Conductivity	* Electrets
* Corona Discharge	* Mobius Strip	* Photophoresis
* Coulomb’s Law	* Magnetic Explosion	* Thermophoresis
* Friction	* Photophoresis	* Triboelectricity
* Diffusion From Limited Source	* Resonance	* Pascal Law
* Boundary Layer Entrapment	* Ferro-magnetism	* Ranque Effect
* Atomic Beam-Stimulated Desorption	* Diamagnetism	* Fluidisation
* Diffusion Depth	* Reuleaux Triangle	* Funnel Effect
* Dopant Segregation	* Laminar Flow	* Electrophoresis

Some of these Effects will turn out to be more appropriate to the problem at hand than others. It is the job of the engineer to determine which is which. This may involve a significant amount of work. As, often, does the process of transforming a promising effect into a viable engineering design.

In some instances, the technology associated with the effect will be insufficient to carry out the specific required function (e.g. gravity alone will be insufficient to separate, say, a 3µm particle from oil. Or at least not in an acceptable (for a filtration system) period). In these cases, engineers are forced into a programme of research to improve the effect, or, more likely, there will be a need to back away from the IFR towards a solution which is viable. (See Reference 8 for an example of how such a process works in practice).

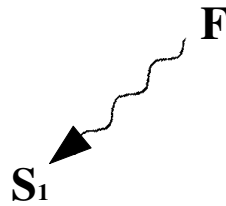
Meanwhile, in the case of the ‘contaminants remove themselves’ Ideal Final Result, it appears that a solution may well be possible.

The problem is amenable to analysis by yet another of Altshuller’s TRIZ tools – the S-Field Analysis part of ARIZ (1). S-Fields are Altshuller’s attempt to describe inventive problems in a manner analogous to chemical formulae.

‘Fields’ are external forces which may be applied to Substances (the ‘S’ in S-Field). There are six basic families of field:-

- Gravitational
- Electromagnetic (electrical/magnetic)
- Nuclear – weak interaction
- Nuclear – strong interaction
- Mechanical
- Thermal

Taking S_1 to represent a typical particulate contaminant, we are able to draw an S-Field for the current situation:-



According to the IFR, we require to impart some kind of force onto the particle in order to separate it from the force. The wavy arrow indicates that this is currently an 'unsatisfied action'. Analysis of the available Fields along with use of the Effects database does not appear as though a (practical) field with sufficient force can be obtained. Probably the closest would be to use an electrical field (cf. electrostatic precipitator separation devices), although the low velocity requirements of such systems means they would be too bulky (and expensive) for a fluid power application.

This 'unsatisfied action' S-Field scenario is one of a number of problem types classified by Altshuller. For each type of problem, Altshuller identified a number of Standard Inventive Solutions. For this particular case, one of the suggested solutions is, 'if it is not possible to impart sufficient Field to the Substance directly, then impart it through a second substance. The S-Field map for this suggestion is illustrated in Figure 9.

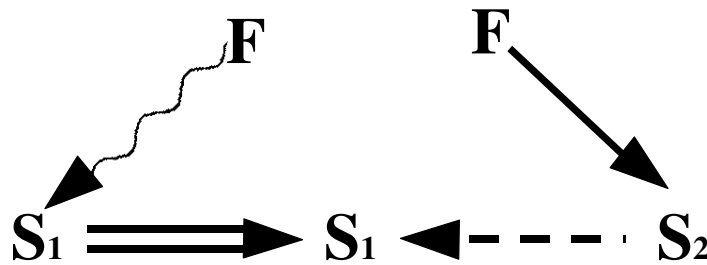


Figure 9: S-Field for 'Ideal Final Result' Fluid Power System Filtration Device

Ideally, the second 'substance' S_2 will be an existing part (or a modification of an existing part) of the system surrounding the separator. Ideally also, the Field applied to S_2 will be the simplest of the six possibilities.

Analysis of the 'self-cleaning filter' based on this S-Field has in fact revealed that a solution does exist. In keeping with the concept of using existing parts of the system (i.e. the overall fluid power system), preliminary calculations suggest that a self-cleaning filter offering:-

- lower installed volume
- lower pressure loss
- higher pressure loading capability
- low part count (lower than for current barrier filters)
- low cost

can be achieved. In common with other studies (9), this case demonstrates a tendency to achieve many more side-benefits above and beyond the initial goal (which was ‘self-cleaning’ in this case) if ‘design without compromise’ can be achieved. A self-cleaning filter based on the S-Field work presented here is currently the focus of a patent application.

4.0 Case Study 3: ‘Ripple-Less’ Gear Pump

Several techniques for the reduction of flow ripple from external gear pumps have been described (10). Such methods include:-

- a) Increasing the number of teeth. In theory, the peak-to-peak flow ripple is inversely proportional to the square of the number of teeth.
- b) Use of well designed relief grooves.
- c) Use of a cam and plunger mechanism operating in parallel with the main pump – with the cam profile designed to produce an inverted image of the pump flow ripple (11).
- d) Use of controlled leakage (12).
- e) Reduction of gear backlash – with the aim of achieving a seal on both leading and trailing edges of the gear teeth – e.g. Dual Flank Engagement (DFE) gear design (13).

It may be seen that each of these solutions has essentially been achieved at the expense of a degradation of some other aspect of the design:-

Number of teeth	- manufacture more complex - strength reduced
Relief grooves	- manufacture more complex/expensive
Cam and plunger	- manufacture more complex/expensive - reliability degraded
Controlled leakage	- degrades efficiency
Reduced backlash	- manufacture more complex - reduced life

Each of these trade-offs represents exactly the sorts of compromise solutions prevalent in design philosophy outside Russia. In TRIZ terms, each represents a Contradiction amenable to analysis through Altshuller’s generic Contradiction Matrix.

Use of the Contradiction Matrix requires conversion of the specific contradictions associated with the problem at hand into the generic contradiction parameters used to construct the matrix (Table 1). In this case, the desire to ‘improve ripple’ most closely correlates to the parameter ‘object generated harmful factors’ in the Matrix. Similarly:-

Manufacture more complex → ‘complexity’, or ‘manufacturing precision’, or ‘shape’

Strength reduced → ‘strength’

Degrades efficiency → ‘loss of substance’

Reduced life → ‘reliability’, or ‘stability of object’s composition’

Each pair of contradictions then gives a number of recommendations from the Matrix regarding Inventive Principles (Reference 14, Table 2) successfully adopted by others in eliminating that particular type of contradiction.

From the seven pairs above, the Matrix recommended the following Inventive Principles as potentially beneficial to the gear pump case:-

- Periodic Action
- Segmentation
- Porous Materials
- Symmetry Change
- Another Dimension
- Copying
- Discarding and Recovering
- Parameter Changes
- Dynamic Parts
- Blessing In Disguise
- Separation
- Preliminary Action
- Intermediary
- Inert Atmosphere
- Composite Materials
- Cheap/Short Living

The case is unusual relative to other cases (15) in that it has generated a rather large number of possibilities. This has two probable implications; 1) that significant analysis may be required, and, 2) that the likelihood of finding a solution is relatively high.

Effective use of any of the Principles demands an in depth knowledge of the ripple causing mechanisms present in the gear pump. Even so, some of the suggested Principles appear somewhat distant ('inert atmosphere' for example) from a possible solution – although the way the brain works (16), it is usually possible to make some form of useful connection (e.g.). Others of the suggested Principles offer perhaps more immediately apparent conceptual solutions:-

Asymmetry – different sized gears, helical gear forms, or (cheaper to manufacture) conventional plain cut teeth plus a local asymmetry on the delivery lip – Figure 10 – asymmetrical gear-root forms (15).

Figure 10: Use of 'Asymmetry' to Reduce Pump Ripple

Separation – physical separation between the pump delivery region and the main source of ripple effect – the area where the gear teeth mesh; Figure 11.

Figure 11: Use of ‘Separation’ to Reduce Pump Ripple

Intermediary – as above, or perhaps introduction of a third gear wheel.

Periodic Action/Dynamic Parts – suggests arrangements like the cam and plunger design.

Another Dimension – as asymmetry, suggests using the third dimension (depth) of the gears or their housing to achieve a solution.

A number of these ideas (and their combination) is currently under evaluation at the University of Bath..

5.0 Conclusions

- 1) The growing importance of effective innovation and the ever-increasing cost of product development both mean significant increases in the responsibility borne by engineers in ensuring we achieve the ‘best’ possible solution to a problem.
- 2) The Russian-based TRIZ inventive solving methodology offers a number of powerful new ways of looking at the design process relative to traditional ‘design is a trade-off’ assumptions. It is quite probably the most effective tool available anywhere to assist engineers in getting to that ‘right’ (compromise-free) design solution.
- 3) Problem definition is by far the most important part of the problem solving process. Altshuller’s Ideal Final Result philosophy provides a means of assisting engineers and designers in this definition process.
- 4) The 40 Inventive Principles of TRIZ provide a very powerful tool for breaking out of existing design paradigms and into new and exciting ones.
- 5) TRIZ methods have been successfully used to derive a patentable ‘self-cleaning’ filter concept design.
- 6) TRIZ methods have been successfully used to develop a number of novel concepts which may help to derive a novel, low-cost, ripple-less gear pump design.

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*"If I had eight hours to chop down a tree, I'd spend six sharpening my axe."
(Abraham Lincoln)*

1. Weight of moving object	21. Power
2. Weight of stationary object	22. Waste of energy
3. Length of moving object	23. Waste of substance
4. Length of stationary object	24. Loss of information
5. Area of moving object	25. Waste of time
6. Area of stationary object	26. Amount of substance
7. Volume of moving object	27. Reliability
8. Volume of stationary object	28. Accuracy of measurement
9. Speed	29. Accuracy of manufacturing
10. Force	30. Object affected harmful effects
11. Tension, pressure	31. Object generated harmful effects
12. Shape	32. Manufacturability
13. Stability of object	33. Convenience of use
14. Strength	34. Repairability
15. Duration of action - moving object	35. Adaptability
16. Duration of action - stationary object	36. Complexity of device
17. Temperature	37. Complexity of control
18. Brightness	38. Level of automation
19. Use of energy by moving object	39. Productivity
20. Use of energy by stationary object	

Table 1: 39 Elements of the Contradiction Matrix

1. Segmentation	21. Skipping
2. Extraction	22. 'Blessing in Disguise'
3. Local Quality	23. Feedback
4. Asymmetry	24. Intermediary
5. Combination	25. Self-Service
6. Universality	26. Copying
7. 'Nested Doll'	27. Cheap/Short Living
8. Counterweight	28. Mechanics Substitution
9. Prior Counter-Action	29. Pneumatics and Hydraulics
10. Prior Action	30. Flexible Shells/Thin Films
11. Prior Cushioning	31. Porous Materials
12. Equi-potentiality	32. Colour Changes
13. 'The Other Way Round'	33. Homogeneity
14. Spheroidality	34. Discarding and Recovering
15. Dynamics	35. Parameter Changes
16. Partial or Excessive Action	36. Phase Transitions
17. Another Dimension	37. Thermal Expansion
18. Mechanical Vibration	38. Strong Oxidants
19. Periodic Action	39. Inert Atmosphere
20. Continuity of Useful Action	40. Composite Materials

Table 2: 40 Inventive Principles