

DESIGN WITHOUT COMPROMISE: A NEW PERSPECTIVE ON REFRIGERATION AND HEAT PUMP TECHNOLOGIES

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ABSTRACT

Design without compromise is about eliminating the design trade-offs Western 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 refrigeration and heat pump industries 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 – often less than 1 or 2% of the total.

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

Pre-1989 Russia did not have to face any significant market pressures for rapid innovation. In addition, the prevailing culture was one of making-do with limited resources. From a design perspective, the name of the game was 'doing more with less'.

Amidst this culture was Patent Engineer Genrich Altshuller. Altshuller had the idea that all of the examples of 'good' design practice – the designs which succeeded in achieving maximum functional benefit from minimum part count – followed common solution

strategies and that these strategies could be systemised. And so Teorija Rezhenija Inzhenernyh Zadach (TRIZ) – or, in English, ‘Theory of Inventive Problem Solving’, was born.

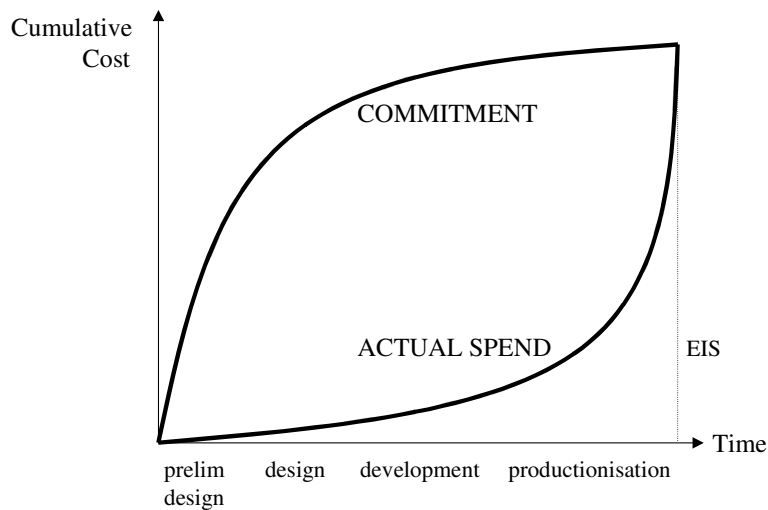


Figure 1: Spend/Commitment Hysteresis

TRIZ research began in 1946 with 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 are repeated across industries and sciences**
- 2. Patterns of technical evolution are 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. In particular, it means first searching for, and then seeking to eliminate the contradictions and conflicts present in designs.

Altshuller’s work on design contradiction 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 – for example (2) - is therefore not surprising.

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:-

- Technology evolution trend prediction tools 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 Contradictions, Ideal Final Result, Effects and Trends of Technology Evolution parts of TRIZ from a refrigeration and heat pump industry perspective, and looks at how TRIZ is being applied to shift a number of design paradigms surrounding seemingly intractable problems.

2.0 CASE STUDY 1: FLANGE 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 generic 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 either increase bolt torque, increase the number of bolts, or to introduce a gasket of some description. 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 all three cases, 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 or adding a gasket has increased the overall weight, cost and maintenance time. 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 requires 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.

An essential element of the work done by Altshuller and his team has been the systematic classification and analysis of these types of design contradictions. By using the global patent database as the basis for such analyses – with something like 3 million successful patents now having been analysed – it has been possible to compile a catalogue of ‘best-practice’ inventive solutions to such contradictions. ‘Best-practice’ being cases where the inventor has eliminated rather than compromised between the conflicting design parameters. In all, Altshuller determined that out of all of the patents considered, there were just 40 generic Inventive Principles (3).

TRIZ sees the formation of generic conflicts (for example, in this case a technical contradiction between **weight** – more bolts – versus **harmful effect** – the seal leaks) into a

Contradiction Matrix (4), each element of which provides a list of the generic Inventive Principles (in this case a Principle known as ‘Another Dimension’) which have been successfully used by others to solve a particular type of design conflict.

Reference 5 details the process by which the flange joint problem may be solved using TRIZ. Needless to say, it is possible to design a better seal with fewer bolts. The answer is illustrated in Figure 2. Tests on this type of flange joint (6) have demonstrated that it is actually possible to halve the number of bolts relative to conventional design practice.

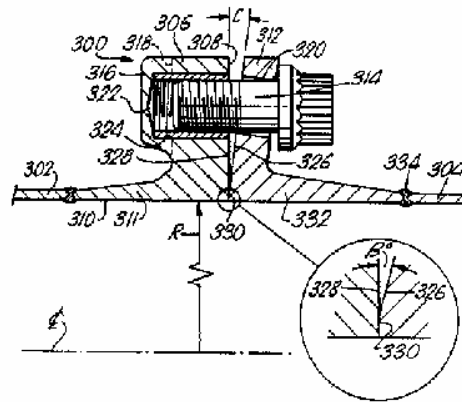


Figure 2: Fluid-Tight Joint With Inclined Flange Face, US Patent 5,230,540

The inclined flange face idea is one which may well be applicable to a number of heat pump and refrigeration industry related product designs above and beyond flange joints.

3.0 CASE STUDY 3: FILTERS

Although not present in large numbers of heat pump and refrigeration applications, protection of system components from either system-generated (e.g. component wear debris in a lubrication system) or environmental contaminants (e.g. blockage of heat exchanger components by atmospheric debris) is a common generic requirement.

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

- * PHYSICAL SIZE - contaminant holding capacity,
- pressure loss versus weight
- * MESH SIZE - circuit protection versus filter life
- * MEDIA TYPE - cleanable versus disposable
- * OPERATING PRESSURE
- * BYPASS

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

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 (7). Miles defined 'ideality' or 'value' as:-

$$Value = Benefits / (Costs + Penalties)$$

The 'law' of increasing product 'ideality' in the context of filters says that future systems will evolve towards greater benefit (better 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 shown in Figure 3. S-curves show trends of increasing ideality through successive generations of product evolution.

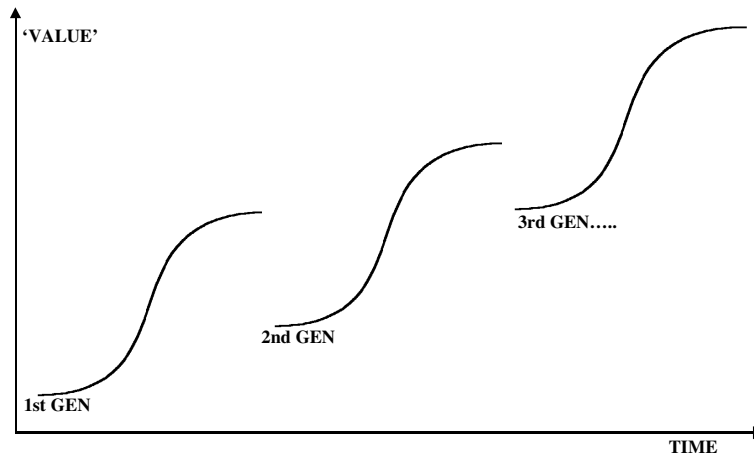


Figure 3: Typical Product Evolution S-Curve

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 4) 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.

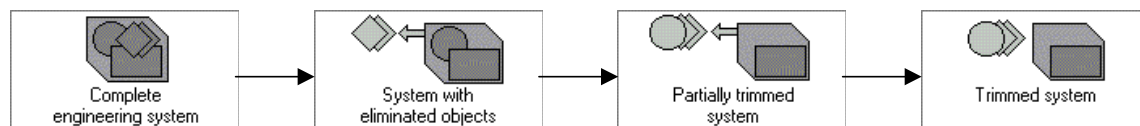


Figure 4: 'Trimming' Evolution Trend

Another trend potentially relevant to the design of filters is 'Surface Segmentation' shown in Figure 5:

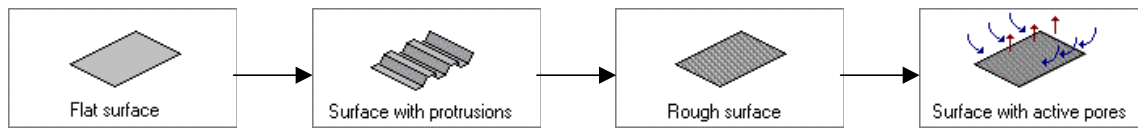


Figure 5: 'Surface Segmentation' Evolution Trend

Thinking now in terms of some of the current filtration system trade-offs and these example evolution trends, it becomes possible to see how recent design evolutions (e.g. 'core-less' filters) have been derived.

Knowledge of the trends makes it possible to predict design evolutions beyond the current state of the art. TRIZ also contains Altshuller's 'Ideal Final Result' (IFR) method of looking at long term product evolution.

There are a number of ways in which the IFR 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 a generic filtration system, the following analysis might 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
- 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)
- 5) **Under what conditions would the interference disappear? (What resources are available to create these conditions?)** - if 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 – currently around 1600 in total. One of the great beauties of what has been done with the database, however, follows from the lead provided by Altshuller in terms of classifying the database in terms of **function**. So, for example, the database collects together all the known ways of making particles move under a single heading. At present, the database contains 33 effects which may be used to move particles:

* 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 a fluid. Or at least not in an acceptable (for a filtration system) period of time. 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. A more complete description of a 'self-cleaning' filter problem analysis – the solution for which is currently the subject of a patent application - may be found in Reference (9).

4.0 CASE STUDY 3: REFRIGERATION COMPRESSOR DESIGN

According to Altshuller's analysis of the patent database, the large majority (77%) of patents fall into a category he described as 'Apparent' or 'Minor Improvements'. He also concluded that a further 18% came from within the same industry sector. The remaining 5% - the most significant advances – came from innovations generated by inventors who had looked beyond the horizons of their industry knowledge base.

A crude analysis of the 200 or so US patents granted for refrigeration compressors since 1971 indicates nothing that Altshuller might have classed as a major discovery. In fact, the patent profile appears symptomatic of a technology at the mature end of its S-curve. An analysis of the patent profile by technology area is nevertheless interesting – Figure 6.

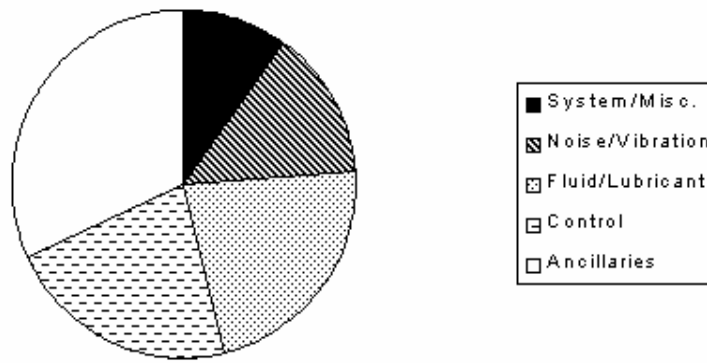


Figure 6: Refrigerant Compressor Patent Profile

The profile raises a number of points regarding the state of the art and the potential for future developments:-

4.1 Noise/Vibration

Noise and vibration is a common symptom of a non-IFR system. Use of reciprocating compression systems inevitably leads to this type of issue. Almost a quarter of refrigerant compressor patents are inventions aimed at curing noise and vibration symptoms. In TRIZ terms, ‘curing symptoms’ is design by compromise. The ‘design without compromise’ approach would see noise and vibration problems tackled by looking at ‘root causes’. In TRIZ terms this might prompt searches for solutions outside the reciprocating piston compressor arena. This is an area considerably beyond the scope of this paper, but it is nevertheless worth mentioning that similar root-cause analysis work on ‘ripple-less gear pumps’ is currently being successfully undertaken at Bath (9).

4.2 Fluid/Lubricant

Apart from the patents relating to non-CFC based fluids, the large majority of fluid and lubricant based inventions relate to either ‘better’ ways of supplying lubricants to moving components, or keeping lubricant and working fluid separate. In TRIZ terms again, these inventions are almost all design compromise based. Several are consistent with the ‘trimming’ trend as might be expected in such a cost-competitive industry – i.e. attempts to achieve more with less – but almost all are small incremental steps and almost none suggest a more radical roots-up design approach. Perhaps the closest is US patent 5,555,956 which achieves elimination of a separate lubricant by having it’s lubricating function performed by another (already existing) part of the system – in this case, the working fluid.

4.3 Control

Almost a quarter of all refrigerant compressor patents since 1971 have related to control issues. An analysis of these patents in relation to another Altshuller technology evolution trend known as ‘Action Co-ordination’ (Figure 7) appears consistent with the evolution of control-related inventions.

The trend correlates quite well with past evolution of, say, domestic refrigerator compressors: First generation ‘non-co-ordinated action’ systems involved the compressor motor being switched on permanently, irrespective of the temperature condition inside the refrigerator. Second generation ‘partial co-ordination’ systems include present day thermostat controlled systems where the thermostat simply turns a single speed motor on or off. Third

generation ‘co-ordinated action’ systems include systems where a thermostat controls a variable speed motor and, more recently, a small number of patents in which the motor speed control responds to temperature change rate as well as absolute temperature level.

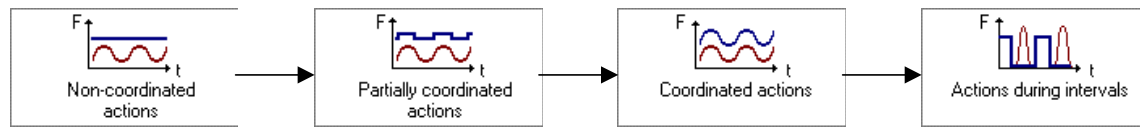


Figure 7: Action Co-ordination' Evolution Trend

There appear to be no patents associated with what Altshuller predicted as the fourth generation in the ‘action co-ordination’ evolution path. I.e. the third generation represents the current state of the art. According to the trend, future refrigerator improvements are highly likely to head in the fourth generation ‘action during intervals’ direction. By way of example of a beneficial improvement to refrigerator systems using an ‘action during an interval’, it is perhaps useful to speculate on a refrigerator system which uses only cheap rate electricity and then possesses some form of energy store to provide the required cooling function outside cheap-rate times.

4.4 Ancillaries

A third of all refrigerant compressor patents relate to inventions surrounding individual component functions. The largest single source of inventive problem solving has taken place in the area of valve design. Almost all patents in this area again follow the small-step, incremental improvement approach common to mature systems.

4.5 Systems/Miscellaneous

Perhaps surprisingly, all of the inventions in this ‘overall system’ class were also relatively small step improvements. In terms of Altshuller’s classification, they all appear to derive from ‘within the industry’. In other words, there does not appear to be any significant read across of technology advances in other industry sectors into the refrigeration sector. This should mean ample scope for large-scale improvements in the future. Perhaps an obvious example of a possible import to the refrigeration sector would be the emerging class of very high speed electric motors.

5.0 CASE STUDY 4: HIGH PERFORMANCE HEAT EXCHANGER

To a considerable degree, the preceding description of TRIZ tools and methods has really only been able to skim the surface of the methodology in its current totality. Whole areas – including ARIZ – Altshuller’s attempt to systemise the innovation process into an ‘Algorithm’ – and his discoveries relating to S-Fields and Standard Inventive Solutions – have had to be passed over for the sake of brevity. Readers interested in finding out more about these topics may care to examine the heat exchanger case study example to be found at Reference 10. The study covers the derivation of a novel heat exchanger design currently the subject of a patent application in the Czech Republic. It provides examples of use of a number of TRIZ techniques in their Invention Machine software implementation.

Using TRIZ and the Invention Machine software, it became possible to systematically identify and then eliminate a number of 'fundamental' heat exchanger design compromises and, in so doing, generate a solution offering the following benefits over the previous best design solution:-

- 100% improvement in effectiveness
- 18% reduction in installed volume
- 14% reduction in mass
- 30% reduction in part count
- large predicted increase in life

6.0 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 the 'right' (compromise-free) design solution.
- 3) Problem definition is often said to be by far the most important part of the problem solving process. Altshuller's 'design without compromise', contradiction elimination and Ideal Final Result strategies provide potent means of assisting engineers and designers in the process of defining the 'right' problem.
- 4) The identification of Contradictions and the 40 Inventive Principles of TRIZ provide very powerful tools for breaking out of existing design paradigms and into new and exciting ones during the problem solving process.
- 5) Predicted technology evolution trends have been used to identify a number of areas into which we might expect filtration systems and refrigeration compressors to evolve in the near-term and long-term future.

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