Case Studies In TRIZ: A Novel Heat Exchanger (Use of Function Analysis Modelling to Find and Eliminate Contradictions)

A version of this paper was first prepared for the First International Conference on Advanced Engineering Design, held in Prague during June 1999. A different version was also presented at the 3rd European Invention Machine User Group Conference in Munich, October 1999.

Bohuslav BUSOV[1], Darrell MANN[2], Pavel JIRMAN[3]

[1] Faculty of Electrical Engineering and Computer Science, Technical University of Brno, Czech Republic

[2] Darrell.Mann@systematic-innovation.com Systematic Innovation, UK.

[3] Department of Glass and Ceramics Machinery, Technical University of Liberec, Czech Republic.

INTRODUCTION

The Russian initiated Theory of Inventive Problem Solving (TRIZ) (1, 2) and those aspects of the Theory implemented in software (3) have begun to penetrate deeply into the development departments of leading, innovative organisations and educational establishments.

Both method and software may be exploited by engineers and scientists during the formulation and solution of technically innovative problems across a truly generic spectrum of technical products, systems and processes.

Problem formulation - often thought to be the most difficult aspect of the innovation process - may be considerably eased through exploitation of the analytical parts of TRIZ; in particular those methods associated with the Russian algorithm for inventive problem solving (ARIZ). In TRIZ-based software, this has been implemented as Function Analysis modules.

Problem solution is greatly assisted through the synthesising parts of TRIZ and its implementation in the software as, scientific effects knowledge-base, Contradictions and Trends of Evolution modules.

The paper discusses the power of both analytical - problem formulation - and synthesising - problem solving - aspects of TRIZ and Computer Aided Innovation tools through use of a case study example from the field of heat exchanger design. In particular, the paper demonstrates how TRIZ was used successfully to break out of existing heat exchanger conceptual paradigms to produce a novel design solution which is now the subject of patent CZ 280 320 B6 (4).

The work on heat exchangers has also raised a number of points regarding how the method may best be taught and used within the education system. A final section in the paper discusses such points in the context of emerging education process paradigms for the next century.

HEAT EXCHANGER COMPONENT ANALYSIS

The paper will concentrate on application of some of the key TRIZ and TRIZ-based software tools and techniques to a real life heat exchanger design example. The heat exchanger is illustrated schematically in Figure 1.

The basic heat exchanger under consideration consists of a mantle, pipes, pipewall supporting pipes, a pipewall movement compensator (necessary in order to take into account pipe dilation effects), and two internal hangers to provide appropriate support to the pipes. The heat exchanger is of the transverse-flow type such that, as shown in the figure, the heating medium enters the mantle at M1 and departs at m1. The heated medium enters the system of pipes at m2 and flows out at M2.
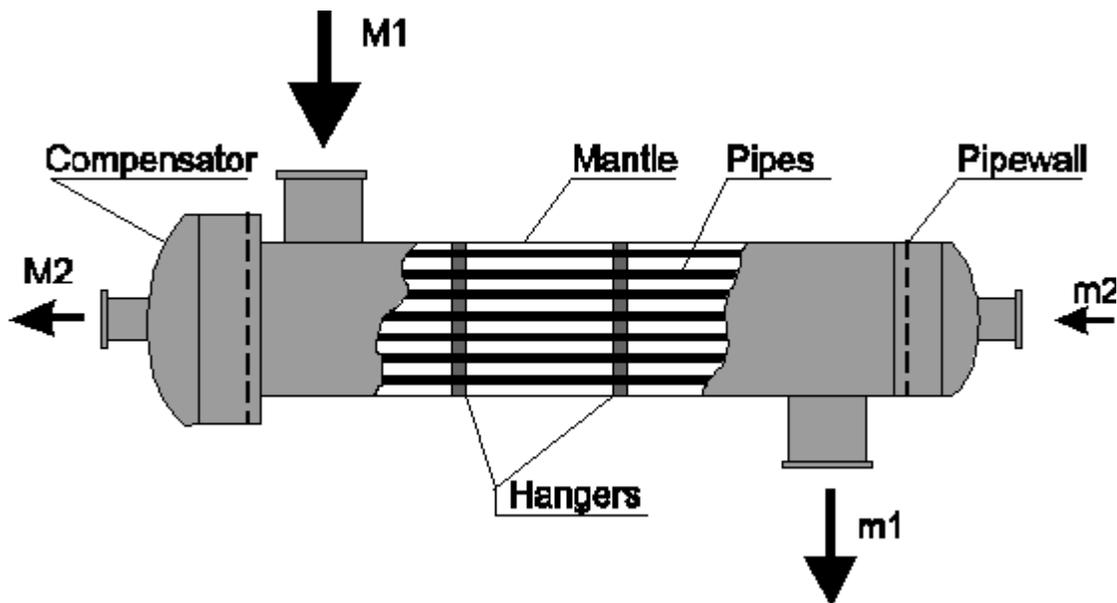

Figure 1: Heat Exchanger Arrangement

In order to identify possible improvements to this basic system, the analytical steps of TRIZ begin with the definition of a functional model of the heat exchanger. In the case of the Invention Machine® TechOptimizer implementation, the method combines the S-Field and Standard Inventive Solutions of TRIZ (1, 2) with the pioneering value engineering thinking of Miles (5).

In both cases, the analysis is based on qualitative descriptions of the relationships between the individual components of the overall system. It collects information about the positive and negative aspects of these inter-component relationships in the form:-

<div align="center">SUBJECT Ù ACTION Ù OBJECT</div>

In each relationship, it is necessary to classify the action in terms of helpful or harmful, insufficient-satisfactory or excessive, directional (one-way, both ways), and time based (continuous, periodic, etc) function. Of primary importance are Function Type and Function Rank descriptions.

In TRIZ terms, Function Types are categorised as either Basic, Additional, Auxiliary or Harmful. Likewise, Function Ranks can be Insufficient, Satisfactory or Excessive.

For the heat exchanger, for example, looking at the mantle and the heating medium M1, we might observe that the functional connection between subject and object is 'conducts'. I.e.

MANTLE Ù CONDUCTS Ù M1

In terms of Function Type, we might chose to classify this relationship as 'Auxiliary' as the transmission of the heating medium of the heating medium through the mantle is subordinate to the basic purpose of the exchanger - which is to transfer heat to 'm2'.

Regarding Function Rank, in this case we will chose to classify the mantle-M1 relationship as 'Satisfactory'. In other cases - for example - if the heat exchanger was suffering from excessive pressure loss of the M1 fluid as it passes through the mantle, we might have chosen to classify the interaction as 'Insufficient' or 'Excessive'.

So, for this particular relationship we have established that the mantle conducts M1 satisfactorily, and that the relationship is auxiliary to the main function of the overall system.

The task of defining these relationships is a vital aspect of the problem formulation process. It is also perhaps the most difficult part. Newcomers to the method may even find it quite un-natural. This is particularly so with respect to the appropriate definition of the ACTION part of the relationship because there are often distinct differences between the language of everyday use and the language of function analysis.

An important rule to help establish whether the action is appropriately defined is to ensure that it changes or preserves something about the object.

For example, 'M1 - heats - pipes' is an appropriate function definition because the action 'heats' does change the object 'pipes' - i.e. 'temperature' changes.

On the other hand, a relationship like 'compensator protects pipewall' is not a valid one because the action 'protects' does not change any parameter concerning the pipewall. 'Protects' is very much the language of everyday use. In functional analysis language, the relationship between compensator and pipewall is far better described as 'compensator releases pipewall' for now the action does change a parameter relating to the pipewall.

There are many actions like 'protects' - such as 'improves', or 'seals', or 'lubricates' - which we have to re-think quite considerably when we are performing function analyses.

Similarly, there can also be problems adequately defining subjects and objects adequately: 'heat exchanger heats m2' for example is valid from the perspective of an action which changes something about the object, but from the perspective of wishing to improve the design of a heat exchanger, is of very little value. Altshuller often talked about super-systems and sub-systems and the importance of establishing the right balance between the different levels within a function model. Others (6, 7) often define a problem in terms of a highly layered problem hierarchy. Pitching the function analysis model at the 'right' level - i.e. the level which will allow the problem at hand to be solved - remains a difficult aspect of TRIZ and software implementations. Meanwhile, Table 1 shows each of the key functional relationships defined for the heat exchanger case study.

Element	Action	Object	Function Type	Function Rank
Mantle	conducts	M 1	Auxiliary	Satisfactory
	supports	Compensator	Auxiliary	Satisfactory
	holds	Pipewall	Auxiliary	Satisfactory
M 1	heats	Pipes	Auxiliary	Insufficient
	elongates		Harmful	
	vibrates		Harmful	
Pipewall	supports	Pipes	Auxiliary	Satisfactory
Compensator	releases	Pipewall	Auxilliary	Excessive
Hangers	supports	Pipes	Auxiliary	Excessive
	impede	M 1	Auxiliary	Excessive
Pipes	heats	m 2	Basic Function	Insufficient
	move	Pipewall	Harmful	
m 2	shortens	Pipes	Harmful	

Table 1: Key Functional Relationships For Heat Exchanger

Adequate definition of the Table is a challenging and time-consuming process. Construction of a supporting component relationship model (Figure 2) can often provide an important aid and ensure that all relevant inter-component relationships are systematically considered.

The Table highlights the function 'pipes heat m2' as the basic function of the heat exchanger. I.e. the main purpose of the device is to transfer heat to the m2 medium. 'm2' in its heated form is the 'product' of the exchanger. Note also that the function has been ranked as 'insufficient' in this example.

Each of the functional definitions where there is one of these 'insufficient' or 'excessive' or 'harmful' actions represents the formulation of a distinct problem to be solved. Effective identification of all such 'negative' functional relationships within a system is essential to the successful deployment of TRIZ Function Analysis methods.
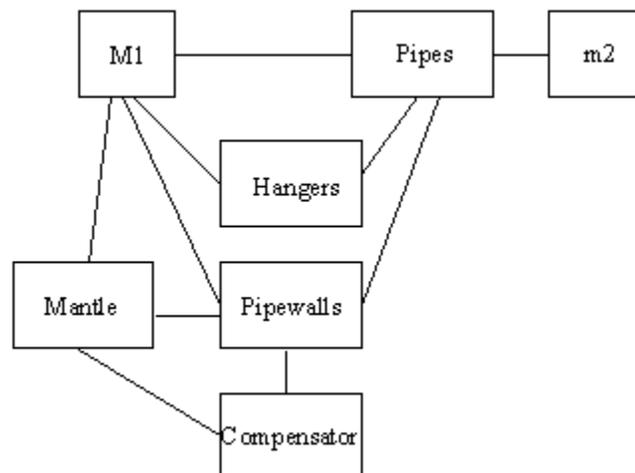

Figure 2: Heat Exchanger Relational Model

For the case study heat exchanger, the functional model and Table have together provided a number of important problem definitions:-

- **Increasing the Basic Function Rank: how might the action 'heat m2' be intensified? (NB includes both heat transfer from M1-to-pipes and pipes-to-m2)**
- **Elimination of Undesirable Effects:**

1. **how to prevent (or how to avoid the consequences) of the pipe elongation when temperatures change?**
2. **how to prevent the pipewall motion inside the mantle as temperatures in the exchanger vary? (NB: the consequence is currently eliminated by the compensator)**
3. **how to prevent pipe vibration? (NB vibration currently eliminated by the hangers)**

Recognising that consumers are, generally speaking, more interested in product function than the product itself, it follows that if it is possible to achieve a given function without a corresponding component, the overall system will benefit. This benefit usually takes the form of a lower cost of production.

This idea of improving the system by preserving the function while removing components was one of the product evolution trends observed by Altshuller's team (1) and as such may be found in both the trend known as 'Trimming' and in his thinking relating to long term product development strategy and the Ideal Final Result concept - where it is very common to envision the IFR of a product to be precisely that it does perform the product function without the presence of the product.

The idea of maintaining (or indeed increasing) functionality while reducing part count (and hence usually cost) is also very much at the foundation of the work on value engineering pioneered by Miles (5).

Central to the value engineering model is the 'value' or 'ideality' parameter, defined as:-

Value = Benefits/ (Penalties + Costs)

The model states that there is an evolutionary trend towards increasing 'value'. Each of the trends observed by Altshuller and his team - including the 'Trimming' trend - may be seen to be consistent with this over-riding, global value trend.

The Product and Process Analysis sections of the TechOptimizer code are in effect an amalgamation of Miles' value engineering approach and TRIZ's systematic analysis approach. Figure 3 illustrates the product analysis model created using the software for the heat exchanger case study.

Consistent with Miles' inclusion of a 'cost' parameter within the 'value' definition, the TechOptimizer implementation also allows the user to specify component cost data. When suggesting ways to improve the system, the software uses this data to help rank and prioritise the individual problems in terms of their net individual effect on the overall system.
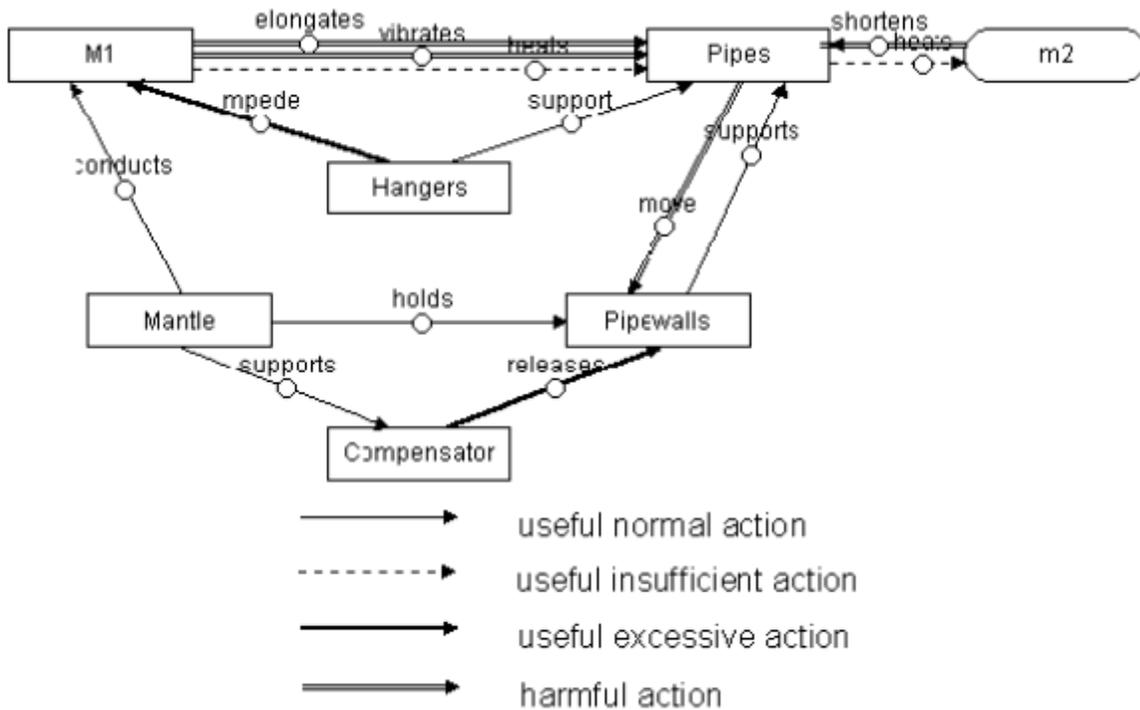
Figure 3: TechOptimizer Model of Exchanger

In this particular case, the overall 'value' calculations indicated that trimming of first the compensator and second the hangers would be most beneficial to the overall exchanger design. In other words, looking back to the previously formulated problems, we should look first at how we might how to prevent the pipewall motion inside the mantle if the compensator is eliminated, and second, we should look at how we might prevent pipe vibration if the hangers are eliminated.

With the function analysis model, we have thus been able to analyse, formulate and prioritise the problems that require solving. We are now in a position to move forward and look at using some of TRIZ's synthesising techniques to generate inventive problem solutions.

ALGORITHM FOR INVENTIVE PROBLEM SOLVING (ARIZ)

TRIZ is a working procedure for the systematic formulation and solution of inventive problems. The primary synthesising tool of TRIZ, ARIZ, is a tactical chain of thinking tools, which together form a clear, identifiable process through problem solutions will emerge. We have previously seen stages 1, 2 and 3 of ARIZ during the problem formulation, creation of a function analysis model and analysis of the model. We will concentrate here on the subsequent problem solving aspects of TRIZ. In these parts of TRIZ, the designer is guided through the solution process from Technical and Physical Contradictions, through to construction and use of Altshuller and team's Standard Principles of Solution.

All of these methods can be seen described in Altshuller's key text (1), numerous examples to be found in TRIZ Journal and elsewhere (7-11), and in the text by Salamatov (2). We will concentrate instead on the application of the ARIZ tools to the heat exchanger problem.

Technical Contradictions

Here we are searching for instances where as we try to improve some feature of the design, another aspect becomes worse. An example may be found in the Figure 3 function model if we look at the M1-vibrates-Pipes part of the model. The vibration is a harmful action adversely affecting the stability of the pipes. Typically, we fit hangers to try and control this stability problem. But, as can be seen from the Function Model segment illustrated in Figure 4, as we introduce the hangers to cure one problem, we have then introduced the problem of hangers impeding the flow of M1.

This is clearly a technical contradiction. Attempts to improve device stability result in a worsened energy loss. The specifics of this problem correlate directly to the generic contradiction parameters defined by Altshuller in his Contradiction Matrix. It is thus possible to directly look-up in the Matrix how other problem solvers have inventively eliminated similar stability - energy loss conflicts.
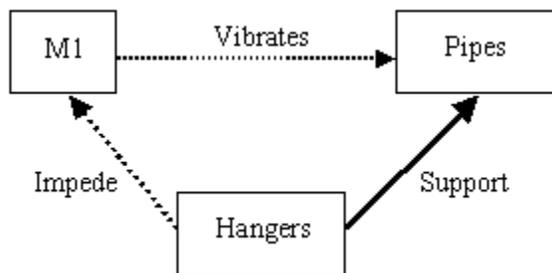

Figure 4: Hanger-Pipe-M1 Interaction Model

The Matrix suggests the following Inventive Principles:-

- *Curvature Increase -* e.g. transformation from 2D surface to 3D space, from lines to curves. This Principle suggests the hangers might take a different cross-sectional form in order to reduce M1 flow resistance.
- *Separation* - interpreted, for example, to mean separating the positive effect of the hangers from their negative effect - e.g. to find another carrier that is able to strengthen the pipes.
- *Multi-Functionality/Universality* - interpreted in this case to mean increasing the functionality of the pipes such that they take on the function of the hangers.

A second technical contradiction exists regarding the desire to increase the heat transfer from M1 to the pipes and from the pipes to m2 - Figure 5.
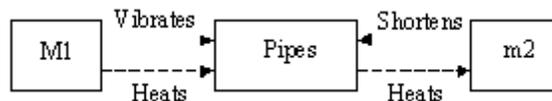

Figure 5: M1-Pipe-m2 Interaction Model

The technical contradiction here is perhaps less easy to see from the Function Model, but one exists nevertheless. In attempting to improve heat transfer from either M1 or to m2, the usual method of achieving the improvement is to increase the area of the heat exchange surface. In other words, we achieve the improvement in heat transfer at the expense of increased physical size.

Translating this specific contradiction to the generic elements of the Contradiction Matrix, we see that the Contradiction exists between area and a linear dimension. The Matrix then suggests the Inventive Principles:-

- *Copying -* interpreted as exploring possibilities relating to use of multiple (smaller) exchangers, and/or a greater number of smaller pipes.
- *Nested Doll -* interpreted as the well known heat exchanger design principle of locating pipes within pipes in the mantle.
- *Preliminary Counter-action -* interpreted as introducing moves to perform an action against the undesirable effect - e.g. the pipes should be 'shortened' to reduce constructional length, while still aiming to increase surface area.

Note: Use of a Function Analysis model - as in Figure 3 - to help identify contradictions is an often powerful problem identification method, albeit one which is currently not immediately apparent from the software implementation.

Physical Contradictions

Physical Contradictions are present when we have contradictory requirements of a single design parameter within the same component or system.

For example, in the heat exchanger, there is a first physical contradiction associated with the pipes -where we require them to be both connected in order to prevent vibration, and to be disconnected in order to reduce resistance of the M1 flow.

A second physical contradiction relating to the pipes also exists, in that we require them to be both long in order to have large heat exchange area, and to be short in order to reduce the overall dimensions of the heat exchanger.

Physical Contradictions are often the most difficult to solve - which may help to explain why many designers prefer to use 'traditional' design trade-off techniques rather than attempt to eliminate the contradiction.

Altshuller's team, however, did identify a number of means of systematically solving Physical Contradictions:-

1. separation of the contradictory requirements in time (e.g. pipes connected when flow conditions are close to resonance, and disconnected when flow conditions are normal - assuming, of course, that both conditions don't occur at the same time)
2. separation of the contradictory requirements in space (e.g. pipes are connected in some places and free in others)
3. alterations to the system structure (e.g. the pipes may be 'connected' by M1 to prevent vibration, but also sufficiently disconnected to allow resistance-free flow of M1, or, the pipes may be made 'long' and 'short' by making them non-linear).

Standard Inventive Solutions

Altshuller and his team have conducted much work on what he called S-Fields (1, 2). S-Fields are an attempt to generate a systematic and universal language for the definition and solution of problems.

In effect, the S-Field method represents a way of classifying different problem types in terms of both the number of interacting components (Substances) and the actions (Fields) which act upon them. TRIZ researchers have classified the different combinations of Substances and Fields possible and subsequently identified Standard Inventive Solutions which may be applied to solve any given Substance-Field combination. In all, 76 such Standard Inventive Solutions have been determined; any three or four of which are most likely to be relevant to a given combination type.

The best way to begin to understand the workings of S-Field analysis is to look at an example. Let us look at the 'M1 heats Pipes' relationship which was earlier identified as an 'insufficient action' in the heat exchanger system. In S-Field terms, this relationship may be drawn as:

$$F_{TH}$$

$$S_1 \leftarrow\ -\ -\ \rightarrow S_2$$
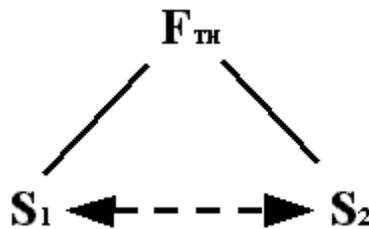
Where S1 and S2 represent the two substances 'M1' and 'Pipes', F represents a thermal field, and the dashed line signifies that the interaction between the two substances is insufficient.

Standard Inventive Solutions recommended for this S-Field class then include:-

   a. Modification of S1 - e.g. use of working fluid with improved specific heat and/or viscosity characteristics
   b. Modification of S2 - e.g. use of different pipe materials, different pipe shape, different surface finish (e.g. introduction of local turbulence-generating geometry features).
   c. Introduction of an additional Field - e.g. introduction of a mechanical field - alter the M1 flow conditions by introducing a swirling flow, increase flow rate to ensure turbulent rather than laminar flow, introduce a heat transfer enhancing vibration force.

$$F_{TH} \qquad\qquad F_{TH}F_{ME}$$

$$S_1 \leftarrow\ -\ -\ \rightarrow S_2 \implies S_1 \leftrightarrow S_2$$
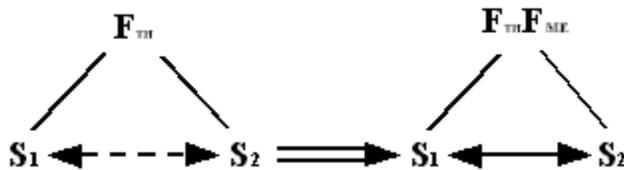
   d. Introduction of a Modified Substance - e.g. add a substance to the fluid M1 in order to increase Field effects
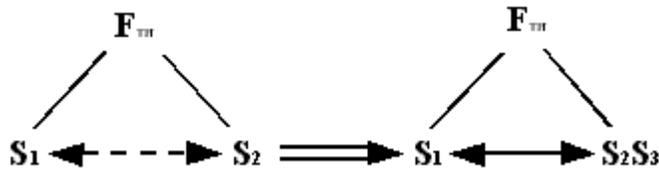
The first three Solutions are commonly employed in a variety of forms in many heat exchanger designs - including the design derived in this paper. The fourth solution family is perhaps less immediately obvious, but, by way of illustration, the TechOptimizer Effects module includes the description of a (patented) heat exchanger concept which sees the introduction of magnetic particles into the working fluid - which are then caused to move relative to the fluid through use of a moving magnetic field. The particulate motion causes a localised increase in working fluid turbulence level and thus creates an increase in heat transfer.

Effects

Altshuller placed strong emphasis on the collation and categorisation of physical, chemical and mathematical effects in mankind's sum knowledge base. By categorising such effects in terms of their function, he generated the idea for a very powerful database. The database has perhaps been most potently implemented in the TechOptimizer software - which now contains close to 6000 known effects and examples, and continues to grow.

Classification by function means that if we have a problem like the one in the heat exchanger where we wish to improve the insufficient action 'pipes heat m2', we are able to do so quickly by examining functions related to the action 'heat'. For example looking up the function 'improve thermal conductivity' in the Effects database, we are able to very quickly establish which effects may be relevant to the specific problem at hand.

Chances are that a good heat exchanger designer may know around a handful of thermal conductivity or heat transfer enhancing effects, and may be willing or able to use only two or three. The TechOptimizer software is able to direct the designer to many more (Table 2):-

• Turbulization	• Transpiration Cooling
• Finned Surfaces	• Resonance Effects
• Bulk flow Direction Change	• Regenerative Systems
• Fluid Vibration - Mechanical	• Ranque Effect
• Fluid Vibration - Ultrasonic	• Ejection Effect
• Acoustic Vibration	• Magneto-Active Bubbling
• Magnetic Control	• Droplet Magnetic-Deformation Effect
• 'Wavy' Walls	• Drop-wise Condensation
• Use of Spiral Geometry Features	• Use of Elliptic Paraboloid Geometry
• Flow Swirling	• Capillary Grooves
• Gravity Assistance	• Dufour Effect

• Porous Metal Construction Method	• Gregorig Effect

Table 2: Example Heat Transfer Enhancing Effects From TechOptimizer Database

The Effects module thus presents engineers with an unparalleled number of design options and means of breaking out of existing and limited-focus design paradigms.

PATENTED HEAT EXCHANGER

What follows is a brief description of the heat exchanger improvements resulting from the above analyses, now patented in Czech patent CZ 280 320 B6 by inventor Msc D Sykora (3).

A schematic illustration of the new heat exchanger is given in Figure 6

In simple terms, the analyses have permitted the elimination of two significant components of the exchanger - the compensator and the hangers - by transfer of the useful functions they performed to other components within the system. In addition, the basic function of the exchanger has been improved, two auxiliary functions have been improved, and four undesirable effects have been reduced or eliminated.
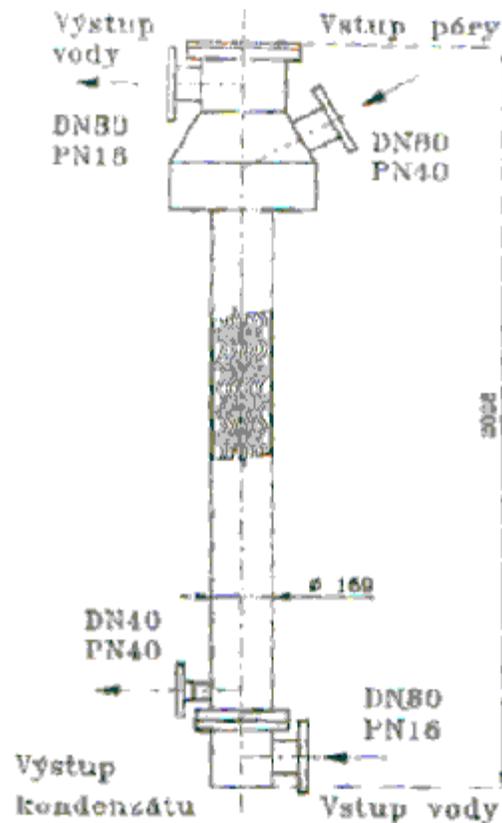

Figure 6: CZ 280 320 B6 Heat Exchanger

A prototype of the novel heat exchanger has now been constructed and successfully tested in the power net system at Brno. Table 3 summarises the overall performance improvements achieved by the invention compared to the previous heat exchanger design.

The following points relating to the heat exchanger design are also worth noting:-

Heater Design	Current	New
Pipe configuration	linear	helical
Number of pipes	37	31
Pipe diameter (mm)	15	15
Pipe thickness (mm)	1	1
Pipe length (mm)	2000	1650
Material	brass	stainless
Heating Surface (m²)	3.0	2.5
Heat output (kW) Steam 1.1MPa, 183°C	720	1335
Heat output (kW) Steam 0.6MPa, 158°C	634	960
Specific heat output a) (kW/m²) b) (kW/m²) c) (kW/kg) d) (kW/kg)	240 211 4.0 3.5	534 384 8.6 6.2
Total mass (kg)	180	155
Temperature dilation solution	bellows	self-comp.
Pipe vibration solution	hangers	pipe contact

Table 3: Comparison of Old and New Heat Exchanger Designs

1. The hangers have been eliminated by making the heating surfaces of the exchanger self-supporting. Elimination of the hangers has also meant a reduction in (non-useful) resistance to the flow of the heating medium. The internal velocity and temperature fields are homogenous.

2. Overall strength is ensured through multi-point, mutual contact of the helical pipes. Vibration is decreased and expected exchanger life is consequently increased.

3. Increased local flow turbulence in and around the helical pipes has created a substantial increase in heat transfer coefficient - thus permitting either a 2x improvement in heat exchanger effectiveness, a 2x reduction in heating surface required, or a combination of the two benefits.

4. The new homogenous heating surface of the helical pipes is self-compensating in terms of handling relative growth and shrinkage between the pipe nest and the mantle.

5. The increased turbulence of the heating medium decreases the localised blocking of the heating surface by impurities and contaminants.

6. The pipe nest forms a highly compact design and so the overall heat exchanger volume may be significantly reduced.

7. The combined effects of 3) and 6) mean opportunities for a decrease in the volume of the surrounding facilities.

8. When vertically oriented, steam condensation occurring in inter-pipe spaces further intensifies the heat transfer effect.
9. The new, shorter, more compact vertical exchanger with the steam condensation mentioned above is more flexible and more responsive to changes in heat output demand.

TRIZ AND ENGINEERING EDUCATION

Courses in the theory and application of TRIZ are beginning to emerge in a number of University syllabi across the world.

When he was teaching and writing about TRIZ, Altshuller placed special emphasis on the need for students to spend as much time as possible actively involved in the use of the TRIZ methods. All taught material needs to be backed up with the provision of extensive case study and tutorial materials. A typical basic final year engineering course may typically comprise 40 to 50 hours of lecture material coupled to at least as much time again for students to practice using TRIZ on case study exercises and problems. More advanced courses will typically then need to place even greater emphasis on practical application of the various tools and techniques.

It is perhaps too early to generalise on the most appropriate means to teach TRIZ due to a variety of cultural and technological differences between nations. A number of important common themes, however, are probably worth noting:-

- TRIZ is complementary to a number of innovative tools and strategies developed outside of Russia. A well-balanced course should take due account of these methods. The world is still some considerable way away from a coherent cradle-to-grave systematic innovation approach. The following tools and strategies, however, have already been seen to offer a high degree of potential for integration with TRIZ:-

    Edward de Bono - the father of lateral thinking has published widely on the subject. Offering students an appreciation of some of de Bono's work is a commonly used way of introducing the general ideas and mind-sets required for effective creativity.

    Quality Function Deployment (QFD) - much potential for working up front of, or in conjunction with TRIZ in terms of problem definition - in particular establishing customer requirements.

    Robust Design - Taguchi based methods most usefully applied in the area between TRIZ and downstream detail design methods. Some investigators (12) have suggested that QFD plus TRIZ plus Robust Design together form an extremely potent whole.

    Design For Manufacture/Design For Assembly - methodology first proposed by Boothroyd (13) to help designers to better understand the economic implications of the design decisions they make. The methodology is highly complementary to the TRIZ 'Trimming' evolutionary trend.

    Multi Criteria Decision Analysis (MCDA) - technique for allowing users to make legitimate 'apples and oranges' comparisons between different parameters

affecting a particular design. Potentially significant common ground between TRIZ and MCDA with respect to conducting trade-offs between alternative TRIZ solutions.

Axiomatic Design - based around the work conducted by Suh (14). Axiomatic design is a technique by which users are able to assess the overall merit of TRIZ-generated conceptual solutions. This work is at a relatively immature stage, but institutions already teaching axiomatic design methods may well find that some integration with TRIZ offers significant benefits.

Failure Modes and Effects Analysis (FMEA) - a powerful method for assisting in the desire to achieve design of reliable products. See also the complementary bottom-up inductive failure analysis methods (15), and the TRIZ-related Anticipated Failure Determination methodology (16).

- Psychological Inertia is a phenomenon which is highly disruptive to the creative process. Making students aware of both the phenomenon and how TRIZ is able to offer systematic means for helping to remove it is an important step before practical exercises are instigated (17).

- As may be seen in the heat exchanger example, there are often several non-instinctive aspects to the language and use of Function Analysis and other aspects of TRIZ. Practice with as many case studies as is practicable is the only reliable means of exposing students to special case uses of the methods. Broad ranging exposure to case study examples is also important from an 'analogies' perspective. 'Analogies' are a commonly used strategy for enabling students to convert TRIZ generic solutions into the specifics of cases related to their own circumstances.

- TRIZ software can provide the basis for a potent educational tool. Experience has found that TRIZ teaching is generally more effective if students understand the manual processes of TRIZ before they become exposed to the software: 'effective use demands effective users'. This is particularly the case in relation to the Principles and Predictions aspects of, for example, the Invention Machine software. Some courses currently make no use of software, while others are beginning to use it progressively more as an integral part of formal lecture material. There is as yet insufficient experiential evidence to propose firm guidelines at this stage, although it is perhaps worth making specific mention of the Effects database contained within the TechOptimizer software; for this is an undoubtedly powerful knowledge source for all students.

CONCLUSIONS

1. TRIZ is an extremely potent systematic innovation tool.
2. The overall methodology contains many useful tools and techniques which may be applied to any number of engineering and non-engineering problems.
3. The paper has demonstrated how those tools and techniques have been used to create a patentable solution to a real-life heat exchanger design case.
4. Effective use of TRIZ tools demands constant exposure and continuous use of the methods to achieve the greatest effect; the methods are distinctly different to most traditional problem solving tools and strategies.
5. The power of TRIZ may be considerably enhanced when used in conjunction with other innovation strategies, methods and tools.

6. Software implementations of TRIZ and other methods as may be found in the TechOptimizer software provide a powerful and user-friendly platform from which to conduct problem solving activities.

REFERENCES

1. Altshuller, G., <u>'Creativity As An Exact Science'</u>, (New York, Gordon And Breach, 1988.)
2. Salamatov, Y., '<u>TRIZ: The Right Solution At The Right Time</u>', Insytec BV, The Netherlands, 1999.
3. Invention Machine Corporation. 'TechOptimizer Professional Edition V3.01', www.invention-machine.com
4. Sykora, D., Patent CZ 280 320 B6
5. Miles, L. D. (1961). <u>Techniques of Value Analysis and Engineering</u>, McGraw-Hill Book Company, New York NY (Latest printing 1989. Published by Eleanor Miles-Walker. Sold through SAVE International, 60 Revere Drive, Suite 500, Northbrook, IL 60006).
6. Mann, D.L., 'Case Studies in TRIZ: A Helicopter Particle Separator', TRIZ Journal, www.triz-journal.com, February 1999.
7. Busov, B., Jirman, P., Dostal, V., 'TRIZ and VEA', study text in Czech, INDUS TRIZ, Brno, 1996.
8. Devojno, I., 'Improvement of the Technical System Using the TRIZ Methodology' (translation from Russian to Czech), teaching text, INDUS TRIZ, Brno, 1997.
9. Kowalick, J., 'Triads: Their Relationship To TRIZ', TRIZ Journal, June1998.
10. Domb, E., '40 Inventive Principles With Examples', TRIZ Journal, July 1997.
11. Zlotin, B., Zusman, A., 'ARIZ on the Move', TRIZ Journal, March 1999.
12. Terninko, J., 'The QFD, TRIZ and Taguchi Connection: Customer-Driven Robust Innovation', TRIZ Journal, January 1998.
13. Boothroyd, G., Dewhurst, P., Knight, W., '<u>Product Design for Manufacture and Assembly</u>', (Dekker, 1994)
14. Suh, N.P., '<u>The Principles of Design</u>', (Oxford University Press, 1990)
15. http://www-osma.lerc.nasa.gov/dfr/dfr.htm
16. Kaplan, S., 'Anticipatory Failure Determination (AFD): The Application of TRIZ to Risk Analysis', paper presented at 10th QFD Institute Symposium, 1997.
17. Mann, D.L., 'Digging Your Way Out of the Psychological Inertia Hole', TRIZ Journal, August 1998.