DESCRIPTIVE PARAMETERS AND CONTRADICTIONS IN TRIZ METHODOLOGY FOR VIBRATION CONDITION MONITORING OF MACHINES

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Summary

TRIZ methodology is a promising innovative tool to obtain various problem solutions, which are close to so called ideal final result - IFR. There are some introductory papers of present author like [Skoryna 10],[Cempel 12], [Cempel 14]. But it seems to be a need to make such an approach from different sides in order to see if some new knowledge and technology will emerge. In doing this we need at first to define the ideal final result (***IFR***). As a next we need to define a set of engineering parameters to describe the problems of vibration condition monitoring (VCM) in terms of TRIZ parameters, and also a set of inventive principles possible to apply on the way to IFR. This means we should present the machine VCM problem by means of engineering descriptive parameters and contradiction matrix of TRIZ. The paper undertakes this important applicational problem and brings some new insight into system and machine VCM problems. It follows from the paper that one can find 17 contradictions and use one set of inventive principles to solve specified contradiction of VCM problem, and also another set of principles to enhance obtained solution.

Key words: machine vibration, condition monitoring-CM, TRIZ, ideal final result-IFR, engineering parameters, contradictions, inventive principles

PARAMETRY OPISUJĄCE I SPRZECZNOŚCI W METODOLOGII TRIZ DLA DIAGNOSTYKI MASZYN

Streszczenie

Metodologia TRIZ jest obiecującym narzędziem znajdywania rozwiązań problemów blisko tzw. rozwiązania idealnego. W diagnostyce maszyn jest już kilka prac na ten temat [Skoryna 10],[Cempel 12], [Cempel 14]. Ale nie jest to jeszcze podejście kompletne i wydaje się, ze jest cos nowego do znalezienia. W pierwszym rzędzie trzeba znaleźć idealny wynik końcowy, na jaki stan wiedzy i technologii nam zezwala. Następny krok to dobór parametrów opisujących problem, a potem w kategoriach tych parametrów znaleźć sprzeczności, jakie nas dzielą od wyniku idealnego. Likwidując te znalezione w pracy 17 sprzeczności korzystamy z zasad rozwiązujących Altschullera'a dopasowanych do diagnostyki maszyn. Robiąc to w pracy znaleziono dwie grupy zasad, takie, które przybliżają nas do rozwiązania i takie, które poszerzają to rozwiązanie.

Słowa kluczowe: drgania maszyn, diagnostyka, TRIZ, idealny wynik końcowy, parametry opisujące, sprzeczności, zasady rozwiązujące

1. INTRODUCTION

During the machine operation (*life*) its condition deteriorates, what one can be observed as evolving faults typical to a given machine type. Condition monitoring of machines (*systems*) is the science and technology for the assessment of condition by means of observation of machine phenomenal field – mostly vibration and temperature, where symptom of condition can be captured and measured and condition inferred (*see for example [Collacott 77]*). This means that we are trying to determine the fault space of the machine, its dimensionality and fault advancement, by observing symptoms of condition, creating in this way machine **observation space**. However, the primary concept of machine condition, the **fault space** of a system (*machine*) can be defined only by some prior knowledge taken from the experience with the other running machines, and the same concerns with symptom observation space.

Fault space of every machine is multidimensional, for example we have usually unbalance, misalignment, bearing faults. Hence, similar multidimensionality is needed in our observation space, and as usually it needs some redundancy too. This is because the symptoms which we measure are usually interdependent, and by means of some symptom processing procedures, we can determine the real dimensionality of observation space and so called generalized fault symptoms (*see for example [Tabaszewski 10]*). These results enable us to infer on the machine fault space and intensity (*advancement*) of the main faults which evolve during the machine operation in its lifetime θ.

Condition monitoring is mostly applied to critical machinery, where by special monitoring system one can observe thermo and vibroacoustical phenomena carrying needed information on system condition. This means that by some measurements of these phenomena and respective signal processing we can create symptom of condition, like for example the velocity vibration amplitude measured at the bearing pedestal, or some other location of machine casing. What is important here that by means of special signal and symptom processing procedures, one can determine the type of fault, and its advancement. We can calculate also the symptom limit value $\mathbf{S_l}$ and symptom reliability **R(S),** which is analogous to lifetime reliability **R(θ)** of the machine [Cempel 91].

In summary, one can say, that having some experience on machine life and running, and a prior knowledge concerning processing of received signals and measured symptoms of condition, one can asses the current machine condition and make forecasting of future condition with a high probability of success. This concerns also the fault type and a date of stopping machine for the renewal, etc. But up to now machine condition monitoring has not been approached seriously by TRIZ[1] practitioners, and the knowledge of TRIZ methodology has not been approached from many sides. Some introductory thinking to connect TRIZ with VCM problems has been already made [Skoryna 10], [Cempel 12], [Cempel 14], etc. And this paper, as a prolongation of previous, deals mainly with determination and assessment of engineering or descriptive parameters, and creation of a full set of contradictions acting in vibration condition monitoring. These contradictions can be resolved next by set of inventive principles defined by TRIZ, approaching closely in this way to ideal final result - ***IFR***. The problem of this paper is to asses the usefulness of descriptive parameters, at first. Secondly, it seems that inventive principles can be used also for the enhancement and betterment of obtained solution of VCM problem. Such is the main purpose of the paper.

2. THE IDEAL FINAL RESULT IN DIAGNOSTICS OF MACHINERY

This type of thinking, looking explicit for ideal final result (***IFR***) coming from TRIZ methodology is not common in machine condition monitoring (MCM). Hence let us imagine, without any restrictions, what we really need here? Self repairing machine, like in military aircrafts, it seems to be too early and too costly. But if we integrate advanced symptom CM system with the machine and with proper signal and symptom processing, our resultant **IFR** can be as follows.

The machine itself is signaling approaching work stoppage, a type of fault, and a time, when it should be handover for renewal.

In order to do this one can imagine that integrated CM system should contain: thermal, acoustic, and vibration transducers with signal preprocessing, in order to form several symptoms of condition $\mathbf{S_i(\theta)}$, n =1,2..n. In this way multidimensional machine observation space is created, which is monitored continuously, and symptom readings are taken with the proper life time distance $\Delta\theta_j$, depending on the machine type and the wearing intensity in a machine [Cempel 91]. These successive symptom readings by VCM system, are forming so called symptom observation matrix (SOM), with columns presenting different type of monitored symptoms[2] and rows giving the values of discrete symptoms readings at lifetime θ_j , $j=1,\dots m$. This rectangular matrix, with the growing number of rows, is the only source of information concerning the overall condition of the machine. One can extract information from it applying for example singular value decomposition (SVD) [Cempel 07], or principal component analysis (PCA) [Tumer 02]. The special processing of SOM can give also symptom **limit value** $\mathbf{S_l}$ which may control the stopping of the machine, and also symptom reliability **R(S)** which assesses the potency of residual running or functional ability of the machine [Cempel 91].

Knowing this one can say that by proper SOM processing method, SVD for example, we are **projecting** the observation space on the fault space of the machine. In this way we are gathering wanted information concerning fault evolution, their types and their advancement.

As the value of many symptoms of condition depends on the current machine load, controlled by a production process, special processing of SOM should be elaborated and taken into account [Cempel 11], [Tabaszewski 10], which gives the results being almost immune against the load variability and other disturbances as well. When these precaution and preparations are successfully applied into the processing of signals and symptom readings in SOM, the defined above IFR of TRIZ seems to be under the reach of contemporary technology of MCM and signal / symptom processing and computation.

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[2] *From one broadband vibration signal, received at some location of the machine body, several symptoms of condition can be created and measured during machine operation.*

3. THE CONTRADICTIONS SUBSET AND MATRIX FOR MACHINE VIBRATION CONDITION MONITORING -VCM

One of the main Altshuller ideas in TRIZ is the formulation of contradictions and **contradiction matrix** enabling to resolve these contradictions by means of the use of inventive principles and other TRIZ tools [Savransky 02], [Orlov 06], [Nakagawa 06], [Mann 04]. The space and the dimensionality of contradiction matrix are defined by a set of engineering parameters describing every innovative problem in given area of engineering. We will take into account at first 39 engineering parameters used in mechanical engineering in its broad meaning, as described in many books and articles concerning TRIZ methodology. Our introductory analysis [Skoryna 10] [Cempel 13] connected with a broad interpretation convinces us, that out of known **39** parameters the ten or even less descriptive parameters will be enough to describe VCM problem properly.

Special comment should be given to choose two newly introduced parameters for condition monitoring; the fault space and observation space, the most important entities in VCM. In a normal interpretation of parameters No **3** and **4** of Altshuller TRIZ, they describe the length of stationary and moving parts of the machine. The length itself is dimensional coordinate, and when the dimension is taken with plural we can have **fault space** of the machine (***Dimension–I***), the primary entity in condition monitoring with the coordinates being the different faults evolving in a machine during its running life θ.

The same reasoning lead us to the second parameter **Dimension-II**, which symbolizes **observation space** of phenomenal field of the working machine, with coordinates being the measured symptoms of condition $S_i(\theta)$, $i=1,\ldots n$. The rest of engineering parameters of VCM of machines are as follows; symptom **reliability**, **accuracy** in detection measurement and processing, **information loss**, **energy loss**, **durability** or lifetime, **ease of use** or running, **repairability** (*maintainability*), and the **temperature** of machine critical parts or casing. Considering the information carried by thermo field of the machine one can notice it is multidimensional spatial information source. While thinking about energy loss as an engineering parameter one can see it is only one dimensional and in many practical cases its dynamics is very low. Hence, we can drop from consideration this engineering parameter and concentrate our diagnostic problem around **9 dimensional** descriptions of many diagnostic problems.

However, in some special cases of working machinery, especially with **variable** load and other working conditions, rotational speed and the like, we must introduce additional descriptive parameter, which can be interpreted like the **speed** of change, variable load, or better the **variability** of working conditions. Narrowly thinking it may be associated with parameter **9** of TRIZ, but it is far more than this. Hence we will introduce additional parameter **40, as variability** of working conditions. So, in a case of unstable working condition we will have **10** engineering parameters to describe our VCM problem, and a contradiction matrix as well.

Having chosen all important descriptive parameters of machine condition monitoring let us think creatively, how to find and express **inherent contradictions** connected with the change of these parameters, which can be encountered in the improvements of machinery diagnostics problems. Some important contradictions are described below in Table 1.

Looking for a ranking of most important descriptive (*engineering*) parameters (*see table 2*) one can see that **fault space** and **variable working conditions** are most important parameters having altogether 5 contradictions to solve. Other important parameters with four contradictions are as follows; observation space, accuracy, information loss. The other three equally important having three contradictions are **reliability, temperature** and **durability**.

Finally engineering parameter with one contradiction is the **ease of running**, so in some cases it can be postponed as descriptive parameter. Hence in such case we will have 9 engineering parameters describing the VCM problem.

This means that normally in VCM we will take into consideration 10 by 10 contradiction matrix, but if needed in some special cases, this dimensionality can be extended easily or diminished a little (*i.e. ease of running, or load variability*). Table 1 shows the one sided contradiction matrix of VCM with marks **V** displaying contradictions between particular engineering parameters. One can see there, that almost every parameter possess at least one contradiction, and some of them have 5 like **fault space**, variable **working condition,** and **4** contradictions for the **accuracy** and **observation space** (*see the table last column*).

It is well known in methodology of invention, and TRIZ as well, that the change of one engineering parameter in the direction of improvement may be the source of worsening of another one, and the only way outside of this loop is to apply some of **40 inventive principles**. Which one to use is usually the matter of careful analogy thinking, and the prior knowledge in the given area of science and engineering.

Table 1. The list of main contradictions (**17**) found in VCM problems

1	The **variable load** of machine influences negatively the **accuracy** of signal detection, processing and symptoms processing.
2	The **variable speed** and **load** can increase the **information loss** in a diagnostic system.
3	The **variable load** and **speed** are against the **ease of use** of a machine.
4	The high **working temperature** is lowering **durability** or residual lifetime of the machine elements.
5	The high **working temperature** is also against **accuracy** of measurements.
6	The high **working temperature** may induce additional **faults** and/or increase the intensity of present faults.
7	The dimension of the **observation space** (*number of symptoms*) makes troubles in calculation of symptom **reliability.**
8	The dimension of the **observation space** (*number of symptoms*) is against **accuracy** of condition estimation
9	The dimension of the **fault space** (*number of faults*) is against **repairability**, it may prolong the downtime of the machine.
10	The dimension of the **fault space** (*number of faults*) is usually against **accuracy** of signal detection, information processing, and symptom processing as well.
11	The high dimension of the **fault space** makes trouble in **reliability** calculation (*assessment*).
12	The higher the dimension of **fault space**, more sophisticated **observation space** should be.
13	The **loss of information** during the machine operation is against its **repairability**, because we may not know exactly, what is going on in a machine, when to stop it and what to repair.
14	Improper choice of **observation space** can increase **information loss**
15	**Information loss** is against **durabilit**y as we can have trouble in foreseeing approaching machine breakdown.
16	**Variable working speed** influences negatively **reliability,** as changing rotation can excite machine internal resonances giving in effect the growing fatigue of material.
17	**Variable working speed** influences negatively **durability**, see line above.

To solve 17 contradictions shown in table 1 and 2, we will use inventive principles of Altshuller, giving them the meaning taken with mechanical engineering area and extended with the knowledge of metrology and the diagnostic signal / symptom processing. The numbering of inventive principles shown in Tab.3 is in accordance with that given in TRIZ references, and its diagnostic meaning and prescribed actions are given below.

1. **Segmentation** – segmentation of the frequency spectrum of vibration /acoustic process, band analysis and /or Fourier spectral analysis, cepstral vibration analysis for gearboxes.
2. **Extraction,** rejection – rejection filters for cutting of unwanted signal interferences, like rotational frequency f_o or the mains frequency 50Hz in Europe.
3. **Local quality** – the use of thermal or acoustic barrier, ear mufflers, isolation of vibration of some part of a machine, the hardening of the shaft ends, also thermal **separation** of machine elements, etc.
5. **Integration,** merging – the vibration transducers with preamplifier, signal preprocessing, wireless transmission, integrated with a machine at specially chosen points and directions.
9. **Prior counter-action** – the forecast of signal distortion and compensation before transmission and processing.
10. **Prior action** – introductory analysis of a fault space (*dimension I*), and symptom observation space (*dimension II*) of the machine, in order to chose probable machine faults, and respective observed processes and a location/ direction of vibration transducers, on the machine body.
11. **Prior cushioning** – safe shut down procedure in rotating machinery diagnostic systems, assessment of symptom limit value $\mathbf{S_l}$.
15. **Dynamics** – vibroisolation, elastic mounts or spacers, in order to diminish or filter vibration transmission inside machine body.
16. **Partial or excessive action** – use of SVD / PCA[3] analysis of SOM to filter noise and obtain singular components /values, also signal demodulation for detection of diagnostic information, and symptom value forecast.
19. **Periodic action** – synchronic averaging of signal, signal sampling with preprocessing, over- sampling of vibration process to detect periodicity and reduce noise.
20. **Continuity of useful action** – constant load of a machine in a production process, constant use of condition monitoring subsystem.
23. **Feedback** – monitoring of diagnostic oriented residual processes of phenomenal field of the machine for the assessment of the machine condition to increase its reliability.
26. **Copying, model** – infrared picture of the machine and / or acoustic map of its surrounding, to reduce preheated / prestressed areas of a machine, symbolic or mathematical model of the machine symptoms evolution, to elaborate its condition recognition and a forecast.
34. **Discarding and recovering** – self balancing systems in rotating machinery, small regulations and repairs during the running of a machine.

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[3] ***SVD***=*singular value decomposition,* ***PCA***= *principal component analysis; for SOM orthogonal decomposition.*

Table 2. Primary contradiction matrix (see **17 V**) of TRIZ for machine vibration condition monitoring (VCM) problem

Directions of contrad. summation ⇓ ⇒	**Fault space** (*dimens.I*)	**Observation space** (*dimens.II*)	**Reliability** (*symptom reliability*)	**Accuracy;** (*detection / measurem/ processing*)	**Variable working conditions** (*speed,...*)	**Informa-tion loss**	**Durability/** *lifetime*	**Ease of use/** *running*	**Repair-ability,** *mainten-ability*	**Tempe-rapture** casing/ element	*Sum of contra-dictions*
1.Fault space (*dimens.I*)	X →	V	V	V	↓				V	V	5
2.Observation space (*dimens.II*)		X →	V	V	↓	V					4
3.Reliability (*symptom reliabil.*)			X →		V						3
4.Accuracy; (*detect./measurem. /processing*)				X →	V					V	4
5.Variable working conditions (*speed,..*)					X →	V	V	V			5
6.Information loss						X →	V		V		4
7.Durability/ *lifetime*							X →			V	3
8. Ease of use */running*								X →			1
9.Repairability, *maintenance*									X →		2
10.Temperature										X →	3

Table 3. Inventive principles (**No**) able to solve and enhance VCM problems in comparison to primary contradictions (V) of table 1.

Improving ⇒ ***Directions of*** ⇓ ***contrad. summ.*** ⇒	**Fault space** (*dimens.I*)	**Observation space** (*dimens.II*)	**Reliability** (*symptom reliability*)	**Accuracy;** (*detection /measurem./ processing*)	**Variable working conditions** (*speed,...*)	**Informa-tion loss**	**Durability/** lifetime	**Ease of use/** running	**Repair-ability,** mainten-ability	**Tempe-rapture** of elem. /casing	*No of inven. principles: different/all*
1.Fault space (*dimens.I*)	**X**→	**V, 5, 10** ↓	**V, 11**	**V, 1, 2**	|[1] ↓		**15**		**V, 26**	**V, 3**	**7/ 8**
2.Observation space (*dimens.II*)		**X** →	**V,1,2,16,19, 20, 23, 26**	**V, 5, 10, 19,9, 26**	↓	**V, 1,2,16 19,20**			**16, 20**	**26**	**10/ 22**
3.Reliability (*symptom reliabil.*)			**X** →	**9, 10, 15, 16**	**V 15** ↓	**1, 9**	**11, 16**	**11, 20**	**11, 16**	**3**	**14/ 22**
4.Accuracy; (*detect./measurem. /processing*)				**X** →	**V, 16, 19, 26** ↓	**9, 15**				**V, 1**	**11/17**
5.Variable working conditions (*speed,..*)					**X** →	**V, 16, 19, 26**	**V 15**	**V, 16, 19, 26**			**4/ 11**
6.Information loss						**X**	**V10**		**V, 10**		**11/14**
7.Durability/ lifetime							**X**	**34, 35**	**34, 35**	**V, 26**	**7/ 9**
8.Ease of use /running								**X**		**3**	**8**
9.Repairability, maintenance									**X**	**3**	**8/9**
10.Temperature of element or casing										**X** →	**3/ 7**

35. Parameters change – change of mass, stiffness and damping (*passive or active*) in order to reduce excessive and harmful vibration and noise, at some parts of a machine.

One can notice from the above that for the solution of 10 by 10 contradiction matrix in machine condition monitoring, we may use **15** inventive principles interpreted in terms of machine use and signal / symptom processing knowledge and technology. They can be used altogether for the best (*see table 2*), or some of them can be omitted due to lack of knowledge (*see principle 9*), technology (*see principle 5*), or lack of need (*see principle 15*).

Looking once more for the inventive principles allocated in the contradiction matrix (*Tab. 2*), and described broadly in above listing, one can say, they present contemporary knowledge and technology of VCM. This includes the broad meaning of the inventing principle No 26, where **copy** may mean also the **model** of the symptoms evolution during the machine lifetime, to make condition assessment and forecast. It can be simple regressive model or much sophisticated with artificial intelligence and model updating [Tabaszewski 10].

What is important here, that it was possible to describe VCM problem by means of minimal number of engineering parameters, and to notice importance of two abstract entities; the **fault space** and **observation space**. We should notice also their common definition and influence on symptom reliability, the ease of running and repairability (*maintainability*) of the machine.

Concerning the problem of minimal dimensionality of engineering parameter set to describe MCM problem, it seems to that minimal dimension of engineering parameter set, can be reduced to a number of **nine** or **ten** parameters only, if needed. Also it is possible to extend this number by other engineering parameters; like accuracy of production (*manufacturability-32*), productivity (39), or harmful side effects (31), in some special cases of machine or engine diagnostics.

Applying TRIZ to MCM area it is also interesting to know which engineering parameters are the most important to define, and solve the contradictions on the way to IFR? To answer this question a special column was appended (*yellow numbers*) to contradiction matrix of table 2, which enumerate the number of contradiction to solve on the way to IFR. One can find the **fault space** and **variable working conditions** have 5 contradictions to solve. Other three engineering parameters; the **observation space** of the machine and also the **accuracy** of detection, measurement and processing, and the **information loss** they include **4** contradictions to solve on the way to ideal final result – IFR of vibration condition monitoring - VCM.

The similar question should be passed when we look for set of inventive principles solving these contradictions. Table 3 shows the numbers of these inventive principles, and some numbers are in shadowed area, when they solve contradictions of table 2. Also there are some additional numbers of inventive principles marked as green, which can help and ease our way to IFR in VCM. What is more to see in a table 3, some principles are encountered a few times. This means they can be applied to enhance our quality of VCM problems solution, and even more some inventive principles, if applied, can solve or enhance not one contradiction only. For example, principles number; 16, 19, 26 (*see table 3*), can solve contradiction **1** of increasing accuracy of signal and symptom processing, contradiction **2** of reducing information loss, and also the contradiction **3** in extending the ease of use and running of the machine.

In summary one can see from table 3, that in 15 cases we use some inventive principles to solve some contradictions, and also we have 14 cases (*green*) of using them without direct contradiction presence. This seems to be good side of the TRIZ application in VCM, that we can find inventive principles to solve contradictions, and also to use them for the enhancement or betterment of VCM solved problem.

4. DESIGN OF VIBRATION CONDITION MONITORING SYSTEM WITH TRIZ ADVICE

Following our consideration and set of inventive principles given in a table 3 let us think how to design simple vibration condition monitoring system for ordinary rotating machine type.

At first we should follow inventive principle **10 prior action** and analyze fault space and find critical faults which should be monitored and eventual foresee the safe shutdown **principle 11**. Next according to principle **5- integration** we will choose a type of integrated vibration sensor with signal preprocessing and wireless connection to processing center of VCM. Knowing the type of critical faults we should monitor signal processing according to **principle 1**, **2, 9** and **19** will be designed and implemented allowing obtaining some set of vibration symptoms. Assuming our machine is not so simple like fan we should use **principle 26** and elaborate some type of diagnostic model of machine, for example a symptom model, and following that a symptom limit value $\mathbf{S_l}$ for each critical fault. For a complex machine we should follow additionally the **principle 16** and elaborate object oriented PCA or SVD symptom processing technique, to allow observation of fault oriented independent symptoms, which will give us small level of erroneous decision. Such set of actions as described above is illustrated shortly in the table 4.

Table 4.The sequence of inventive principles application in design of VCM system and procedures according to TRIZ

Invent. principle numb. and name	Prior activity or work to be done by a system
10 –prior action	Introductory choice of fault space and observation space for a given machine type
11- safe shutdown	Determination of symptom limit and alarm values, design of shutdown system, implementation of shutdown procedure
5- integration	Choice of vibration transducer/ amplifier/ preprocessing/ wireless signal transmission types and models
1-segmentation, **2**-extraction, **9**-prior counter action, **19**-periodic action	Design of signal processing techniques to obtain a set of vibration symptoms creating machine observation space
26 – copy, or symptom model	Establishing the cause – effect relation for evolution of faults and symptoms
16 – partial / excessive action	Application of symptom processing (*PCA/SVD*) to symptom observation matrix –SOM, to obtain generalized fault symptoms and identification of approaching machine stoppage
20- continuity, **23** – feedback	Continuous monitoring of residual processes of the machine to assess its faults advancement

The rest of inventive principles, namely No. **15, 3, 34, 35**, are not necessary for the typical VCM system, and can be implemented for some special machinery type, allowing increasing the machine reliability and accuracy of diagnostic decisions.

5. CONCLUSIONS

It follows from the above it was possible to transfer creatively the current science and technology of machine vibration condition monitoring into the formal TRIZ tools and goal that means to the ideal final result (***IFR***). Due to that, the relative importance of the definition of problem descriptive parameters, machine fault space and observation space has been elucidated, and taken into account. Also it has been proposed that the minimal number of engineering parameters for VCM problem description and solution can be taken as ten parameters, including the most important observation space and the reliability of the machine.

The number of engineering parameters depends on the type of machinery, when the operating condition are mostly stable, like in turbosets, we can use **9** description parameters, but having machine with variable operating condition we should use **10** engineering parameters and respective contradiction matrix. In order to solve contradictions present in MCM problem one can use altogether **15** inventive principles with the **14** mostly used. And when using proper dimensionality of observation space and software for SOM processing and decomposition we can make machine condition assessment and forecasting with a reasonable accuracy.

The paper reveals one more feature of TRIZ important to VCM, mainly one can use one set of inventive principles to solve contradictions, and another set of inventive principles for the betterment of obtained solution.

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