TECHNICAL CONTRADICTION CONTROL ON INVENTION PROBLEM

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Summary. On base cusp catastrophe is offered control problem of technical contradictions on algorithm of inventve problem solving

Introduction

The First part of the algorithm of inventve problem solving (ARIZ-85B) [1] is a process of technical contradiction programmed control. Step by the step of control the technical contradiction passes stages of giving birth, peaking and resolving.

Resolving of contradiction are a jump through the psychological barrier in the consciousness of inventor, but in the technical system is a making a new technical deciding, in particular, invention, which is possessing other characteristics in contrast with the prototype.

Jamp changing of the system characteristics studies a catastrophe theory [2], [3]. There is ensemble of mathematical disastrous process models in technical, biological, social systems, including, papers on the technical creation analysis and using a catastrophe theory in Theory of Inventve Problem Solving [4], [5].

Difficult problem of catastrophe analysis is a choice of state coordinates and control parameters on model of technical creation. In particular, paper [4] is used cusp catastrophe, in which state coordinate is inventing ideality, but control parameters are abstractiveness and time. One minimum of potential function is interpretted as idea of prototype, but other - as idea of invention. Jamp over maximum (psychological barrier) of potential function is motion from idea of prototype to idea of invention.

Given paper is offerred to research more objective subject: a technical system developping model. Inventor controls a process of thinking and gets this model by the algorithm of inventve problem solving in the form of the technical contradiction. Therefore, on the one side technical contradiction is technical system developping model; on the another side technical contradiction is an invention-thinking model. G. Altshuller studied patents (i.e. technical system models) and has got a method of technical creation (i.e. ARIZ). We shall study ARIZ and shall get mathematical technical contradiction model. This model will help us to explain a control of consciousness in technical creation.

Consider mathematical model of step-by-step process of technical contradiction control.

Steady-state control

Shall suppose that problem model is characterized by the state coordinate *z*. Stationary coordinate positions are defined by the equation for the Riemann-Hugoniot surface in cusp catastrophe

$$z^3 - \lambda z - \mu = 0. \qquad (1)$$

The two control parameters are called **λ** and **μ.** Values *z*, **λ** and **μ** until determined, but potential function is defined by the expression

$$V(z) = 0{,}25\, z^4 - 0{,}5\, \lambda\, z^2 - \mu\, z. \qquad (2)$$

Analysis of invention problem occurs in First part of the algorithm of inventve problem solving.

Step 1.1 form invention prototype model. Prototype possesses capacity to work, so from standpoints of catastrophe theory such system has a single equilibrium state, which is a stable position. It is possible get in the equation (1) single and stable equilibrium state by choosing approach image of value of control parameters **λ** and **μ**, for instance, $\lambda < 0$ and $\mu = 0$. This equilibrium state corresponds minimum *Vmin* to potential function $V = V(z)$ (Fig. 1). In this case collection of parameters **λ** and **μ** define subcritical domain of cusp catastrophe.

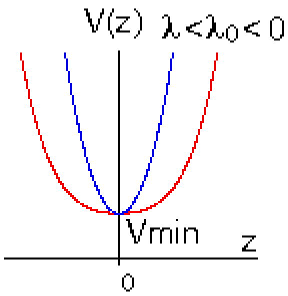

Figure 1

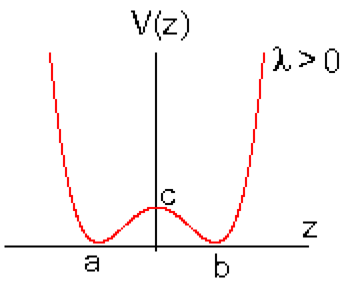

Figure 2

Let, potential function minimum defines a value of undesirable effect of prototype. For excluding an undesirable effect a prototype must get through the catastrophe. Choose other value of control parameter **λ,** for instance, $\lambda > 0$. Then single equilibrium state is destroyed in the equation (1). It becomes unstable, but appear two new stable equilibrium states (Fig. 2). Stable positions give two minima to potential functions (points *a, b*); unstable position gives a maximum (point *c*). In this case collection of parameters **λ** and **μ** define above-critical domain of catastrophe.

Technical contradiction is formed on Steps 1.2 and 1.3 of the algorithm of inventve problem solving. Technical contradiction is kept useful and harmful action of tool to article. When the tool bases in one condition, first action useful, but second action harmful. Under opposite condition of the tool first action becomes harmful, but second action becomes useful. Thereby, one condition of tool gives first technical contradiction (TC1) , opposite condition of tool gives second technical contradiction (TC2).

Let, one stable stationary state of coordinate *z* is one condition of tool (this is *a* point), but other stable stationary state - an opposite condition of tool (point *b*). It is clear argument *z* (state coordinate or conflict coordinate) of potential function *V (z)* must be the condition of tool. If $z=a$, there is one minimum undesirable effect (for TC1), if $z=b$ there is other minimum of undesirable effect (for TC2).

Catastrophe curve $\boldsymbol{\mu}_{cr}=\boldsymbol{\mu}_{cr}(\boldsymbol{\lambda})$ is half-cubic parabola with the point of return (fig. 3), looking like the bird beak. Above-critical domain of catastrophe situated inwardly beak, subcritical domain of catastrophe situated outside of the beak. Then prototype is located on point Step 1.1 ($\boldsymbol{\lambda}=\boldsymbol{\lambda}_0$) of subcritical domain of catastrophe. Increasing the parameter **λ** means a moving an algorithm along Steps 1.2 and 1.3 ($\boldsymbol{\lambda}=\boldsymbol{\lambda}_1$) to Step 1.5 ($\boldsymbol{\lambda}=\boldsymbol{\lambda}_2$). Technical contradiction appears on critical point ($\boldsymbol{\lambda}=\boldsymbol{\lambda}_{cr}$). Critical point is crossing a moving the algorithm and catastrophe curve.

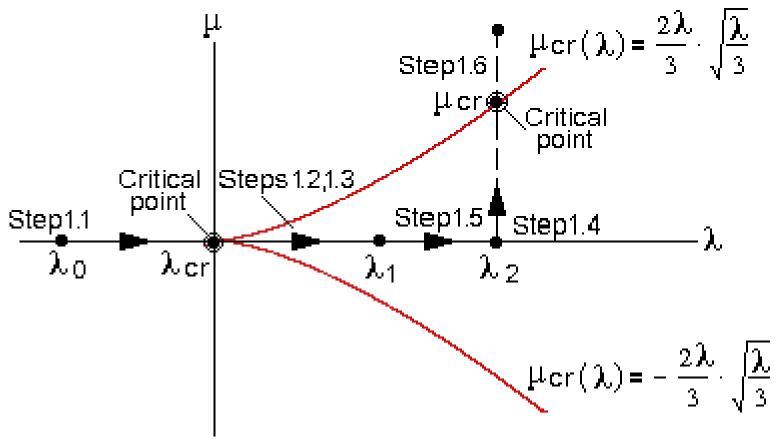

Figura 3

It is important changing the parameter **μ** not bring a technical contradiction under any value of parameter **λ**. Only changing parameter **λ** from -∞ to +∞ always brings the technical contradiction on critical point under any value of parameter **μ**.

The parameter **λ** is called the splitting factor of cusp catastrophe. Shall consider the parameter **λ** split the technical contradiction on two halfs: TC1 and TC2 after the critical point. Increasing the parameter **λ** intensifies a conflict of technical contradiction inwardly above-critical domain of catastrophe: increases both distance *d* between two minima, and decreases value of undesirable effect *Vmin* (Fig.4). Parameter **λ** has dimensionality of square-law coordinate z, so it can be considered as conflict "area". Thereby, it is proportional quadratic coordinate ($\lambda \sim z^2$) like that, as electrical power is proportional quadratic electrical voltage ($P \sim U^2$). So parameter **λ** can be named by the **Conflict Power** (or conflict intensity). Conflict power is important Substance-Field Resource of tool and technical contradiction (it is named Conflict Peaking Resource). Than more conflict power becomes, that is more intensified technical contradiction. Conflict power is a negative value before the conflict, so its value **λ** can be considered as a stability margin of prototype. Than prototype has a more stability margin, that potential "well" has more slope of branches (fig.1). Thereby, it is difficult prototype come out of potential "well", or it is difficult prototype penetrates through the psychological barrier.

Step 1.5 of algorithm means reinforcement of conflict by choice of extreme conditions of tool. This choice occurs by increasing of conflict power from λ_1 before λ_2 in fig.3. Note sequence of Steps 1.4 and 1.5 is changed in contrast with the algorithm. End of Step 1.5 or beginning of Step 1.4 is a border between the life of conflict and its death. Some researchers allow such circumstance [6]. This sequence (1.5 -1.4 -1.6) reflects a more smooth logic of thinkings.

Resolving of contradiction occurs in 1.4 and 1.6 Steps by means of change of other control parameter **μ**. Steps 1.4 and 1.6 can be named by solving steps.

The Step 1.4 of algorithm is an alternative choice equilibrium state (or alternative choice minima to potential function or alternative choice contradictions: TC1 or TC2).

Jump the conflict power through the critical point λ_{cr} from $\lambda_0<0$ before $\lambda_2>0$ and $\mu=0$ brings a system in the unstable equilibrium state (point *c* in the fig. 4). System can not base in the unstable state, so it is dumped in that or other state of stable balance (points *a* or *b* in the fig. 4). A priori it is unknown which state will choose system after bifurcations. It is important in catastrophe theory. A posteriori it is known which state will choose system. Consequently, we have got a new knowledge.

Model (2) must have a single stable state, only then invention will be realized and runnable. Sign of control parameter **μ** brings one or other stable state (one or other TC). Choosing of sign **μ** defines direction of motion of algorithm and depends on the Main Manufacturing Process.

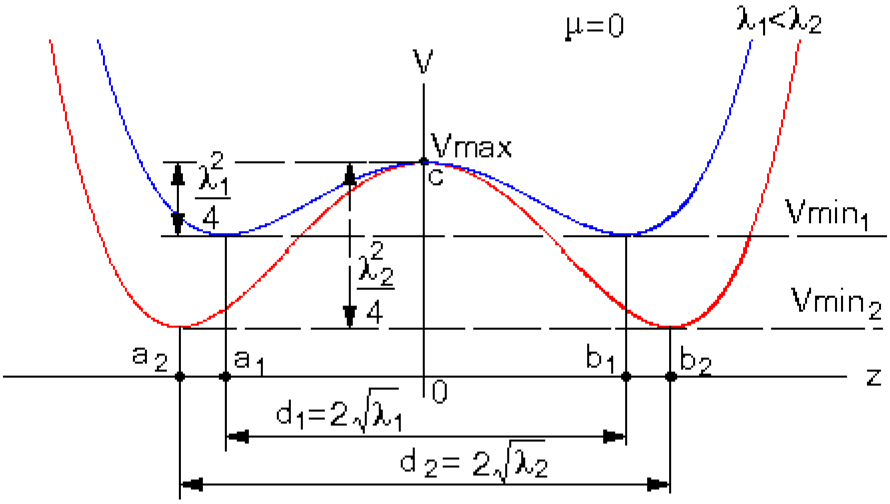

Figura 4

The Step 1.6 of algorithm is final resolving of technical contradiction. *X*-element (unknown element) appears and moves the model into subcritical domain of cusp catastrophe with one stable equilibrium position. Consequently, value of control parameter **μ** must characterize Substance-Field Resource *X*-element and Conflict Resolving Resource. Parameter **μ** is proportional cubic coordinate (**μ**~ z^3), then **μ** can be named by the **Conflict Volume.** When absolute value of parameter **μ** grows, conflict is weakenned, because we are deleted from the point of uncertainty (**μ**=0). Parameter **μ** breaks symmetry the curve to potential functions (Fig.5): one minimum goes up, other minimum goes down. Conflict is resolving after $\mu=\mu_{cr}$, one minimum disappears, other minimum is saved and becomes less in contrast with the prototype.

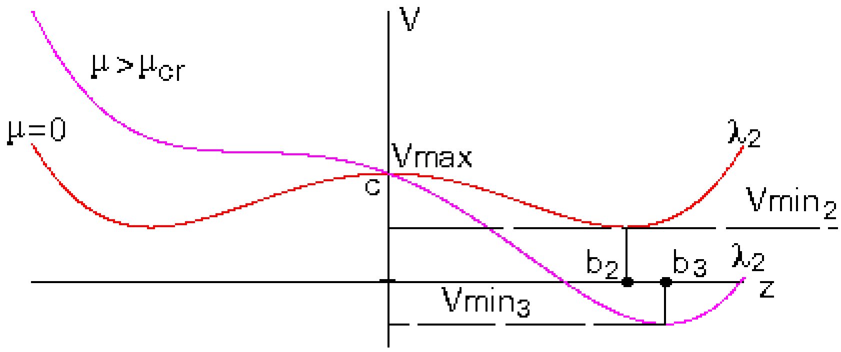

Figura 5

Step-by-step control forces the problem model twice to cross catastrophe curve (**$\lambda = \lambda_{cr}$** and **$\mu = \mu_{cr}$**). The First phase has one stable equilibrium state. The Second phase has two stable equilibrium states. The Third phase has one stable equilibrium state once again. There is the law of system evolution here [7]: Mono-Bi-Transition, next convolution Bi to Mono with another properties.

Consider a direct sequence of algorithm on Steps 1.4-1.5-1.6 (Fig.6).

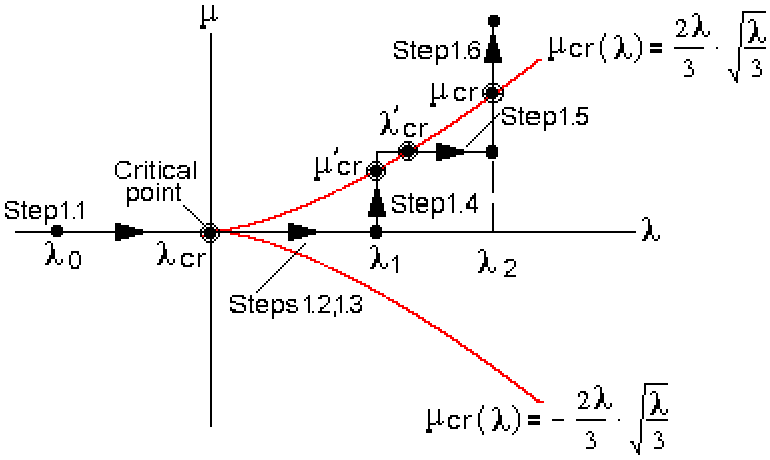

Figura 6

If Step 1.4 is an alternative choice of technical contradiction, after the choice there is single stable equilibrium position, i.e. problem model crossed catastrophe curve (point **μ'_{cr}**) and is renderred inwardly subcritical domain. Step 1.5 is a reinforcement of conflict. Conflict can exist between two positions of tool only. Therefore, step 1.5 expects tacit existance of two contradictions once again. By means of increasing **λ** the problem model once again crossed the catastrophe curve (point **λ'_{cr}**) and is renderred inwardly above-critical domain. Finally Step 1.6 removes the problem model through the critical point **λ_{cr}** into subcritical domain. It is clear the direct sequence (1.4-1.5-1.6) of ARIZ reflects a non-smooth logic of thinkings. Such logic can be named by the oscillatory (or resonance) logic. Resonance logic is Mono-Bi-Poly-Transition and such logic well shakes psychic dead spaces.

Conflict Density ρ can be named ratio **λ** to module **μ** (**$\rho = \lambda / |\mu|$**). Conflict density is a degree of peaking of conflict. Than more **ρ**, that more strong conflict. Conflict power density looks like the degree of ideality in the law of increase of the degree of ideality [7]. If **$\lambda \to \infty$**, tool executes to the best advantage function delivered of a positive effect. If **μ**=0, problem is solving without expenseses of Conflict Resolving Resource and Substance-Field Resource of *X*-element. There is an ideal conflict at the **$\rho = \infty$**. Ideal conflict can be not realized, since point **μ**=0 is a point of unstable equilibrium inwardly above-critical domain. Conflict is resolving, when absolute value of parameter **μ**

increases and reaches a critical value μ_{cr}, but conflict density reaches a critical value ρ_{cr} too.

Critical conflict density ρ_{cr} can be named ratio λ to module μ_{cr} ($\rho_{cr} = \lambda / |\mu_{cr}|$). Substitution $\mu_{cr}=\mu_{cr}(\lambda)$ gives plot "ρ_{cr} -λ" (Fig. 7).

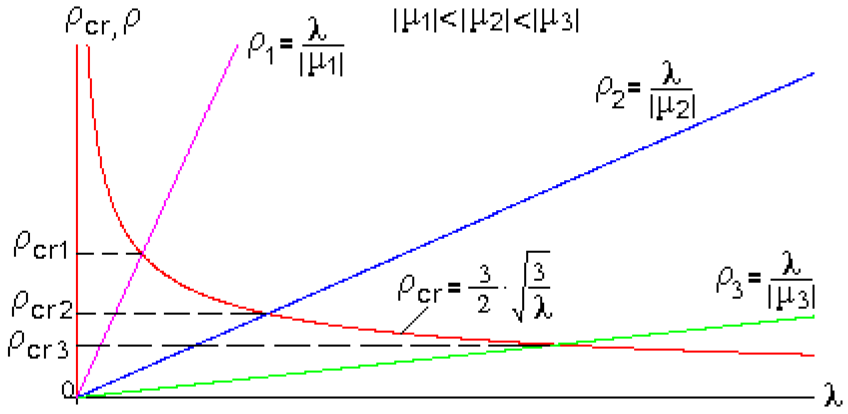

Figura 7

Family of conflict density straight lines ($|\mu|$ =Const) is submitted for figure 7 too. When conflict density reaches critical density, contradiction is resolving. Consequently, critical density can serve measure of problem solving force. The critical conflict density is more value, the Conflict Peaking and Resolving Resources are consumed less and the solving is more strong.

Example

Consider known problem on soldering ampules with medicine [8]. Capillary needed to seal after filling an ampule by fluid medicine. Flame of gas burner seals ampule capillary (Fig.8).

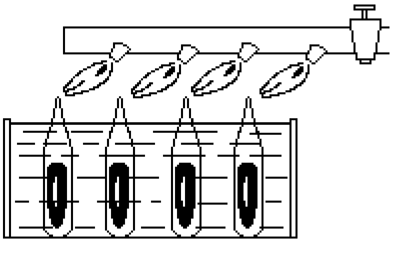

Figura 8

Flame blazes irregularly, so there are defects sometimes. Technical contradiction is formed as follows. If flame is greater, the ampule is sealled well, but medicine is overheated; if flame is small, the ampule is sealled bad, but medicine is not overheated. Flame is a tool, but ampule with the medicine is an article. The location of ampules in water and extremal reinforcement of flame is contradiction resolving. Water is a cheap X-element.

Let length of flame is z-coordinate of cusp catastrophe. Take a next hypothesis for numerical simulation. Long flame has length z_l=4 cm, short flame has length z_s=2 cm, very long flame has length z_{vl}=5 cm, very short flame has length z_{vs}=1 cm. Average length of irregular flame is z_a =3 cm at prototype. Percent of fault ampules is a potential function of catastrophe. Fault ampules have a bad soldering or overheated medicine. Then summands must have procentage dimensionality in the equation (2). Enter propotion factor g, which does equal dimensionality between centimetres and percents. Consequently, factor g have dimensions of %/cm^4.

Distance between minima of potential function (Fig.4) on the Step 1.3 is $d_1=z_l - z_s$ = 2 cm. Then conflict power is $\lambda_1=0.25\ (d_1)^2$= 1 cm^2. Intensify a conflict on the Step 1.5. Distance between minima of potential function on Step 1.5 is $d_2=z_{vl} - z_{vs}$ = 4 cm. Then conflict power is $\lambda_2=0.25\ (d_2)^2$= 4 cm^2. Maybe, conflict power (or conflict "area") is proportional contact area between flame and ampule at the problem.

Shift a potential function curve along axis of abscissas at a distance z_a =3 cm. Then potential function minima will be localized on points z_{vl} and z_{vs}, but potential function is defined by the expression

$$V(z) = (0{,}25\ (z- z_a)^4 - 0{,}5\lambda(z-z_a)^2 - \mu\ (z-z_a))\ g + C, \qquad (3)$$

where value C gives a defect percent at the prototype. Let C is equal 6%.

Choose very long flame (i.e. right minimum of potential function) on the Step 1.4. Consequently, conflict volume is a positive value ($\mu>0$).

Enter the X-element (i.e. water) on the Step 1.6. Critical conflict volume is equal $\mu_{cr} = 2\ \lambda_2\ (\lambda_2/3)^{0.5}/3$=3.079 cm^3. It is clear, there is correlation between critical conflict volume and water volume at given problem.

Left minimum $V(z)$ disappears after the conflict resolving (Fig.5). Right minimum $V(z)$ is lowerred and becomes a percent of fault ampules at the new invention. Let this percent is equal 0.5%. Substitution $V(z)$=0.5%, $z=z_{vl}$ =5 cm, z_a=3 cm, $\lambda=\lambda_2$=4 cm^2, μ=3.1 cm^3 >μ_{cr}, C=6% gives value g=0.539 %/cm^4.

Critical conflict density is equal ρ_{cr} =1.299 cm^{-1}.

Dynamic control of contradiction

Any canonical catastrophe (in particular, cusp catastrophe) gives a steady-state problem model. Algebraic equation (2) allows us to find stationary states a conflict coordinate z only. It is impossible to find transition process $z=z(t)$ between stationary states, where t denotes time. Transition process is a moving process and depends on inertia of inventor thinking. Differential equation is a mathematical moving process model. It is necessary to have differential equation of dynamic technical contradiction.

Catastrophe theory studies so-called gradient systems. Gradient system tends to the minimum of its potential function under $t \to \infty$. Antigradient of potential function gives a direction and spatial velocity of coordinate motion to the minimum point. Antigradient is defined by the expression: $-\mathrm{Grad}V(\mathrm{z}) = -\partial V(z)/\partial z$ and is equal zero on potential minimum point. Since coordinate z is a scalar value on the cusp catastrophe, antigradient module is a spatial velocity of coordinate z. Equality up to a constant of spatial velocity and time velocity brings a simplest dynamic model, i.e.

$$\boldsymbol{\lambda} T\, dz/dt = \boldsymbol{\lambda} T\, \dot{z} = -\partial V(z)/\partial z = -z^3 + \boldsymbol{\lambda} z + \boldsymbol{\mu}. \qquad (4)$$

Time constant T defines thought process inertia.

Operator notationan equation (4) is defined by the expression

$$\boldsymbol{\lambda} T\, sz = -z^3 + \boldsymbol{\lambda} z + \boldsymbol{\mu}. \qquad (5)$$

Value s is differential operator ($s=d/dt$).

Equation (6) is complemented by the time-lag element taking into account information propagation delay of thought process.

$$\boldsymbol{\lambda} T\, sz = (-z^3 + \boldsymbol{\lambda} z + \boldsymbol{\mu})\mathrm{e}^{-\boldsymbol{\tau} s}. \qquad (6)$$

Time-lag element has transfer function $\mathrm{e}^{-\boldsymbol{\tau} s}$. Value $\boldsymbol{\tau}$ is time delay. Under $s=0$ differential equation (5) has a steady state $-z^3 + \boldsymbol{\lambda} z + \boldsymbol{\mu} = \mathbf{0}$, which complies with the algebraic equation (2).

Figure 9 presents a simulation scheme of dynamic contradiction. The simulation scheme received from the equation (6). Conflict is controlled by two input signals. Generator 2 generates a conflict power $\boldsymbol{\lambda}$, generator 1 generates a conflict volume $\boldsymbol{\mu}$. Output of integrator is a conflict coordinate z.

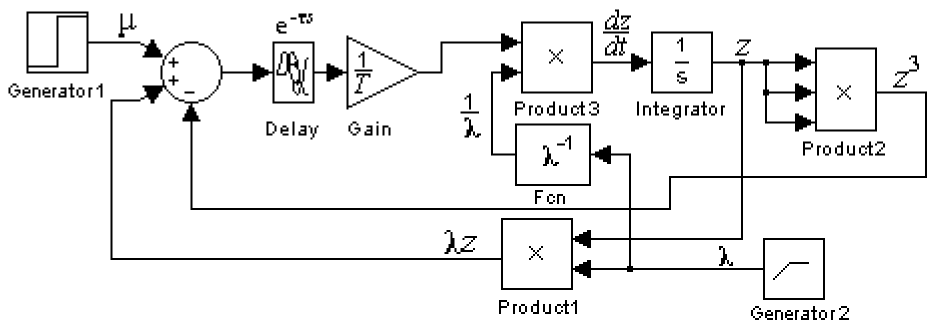

Figure 9

Numerical integration uses input data on ampule soldering (see above example). The current time t is measured in arbitrary time units (abbreviated notation is atu). Thought process inertia T is choosing equal 1.25 atu. Information propagation delay of thought process **τ** is choosing equal 0.6 atu. Hypothetical uniform increasing of conflict power is used. Rate is 1 cm^2/atu. Staircase characteristic simulates a conflict volume. Initial stability margin of prototype is **λ**(0)=- 4 cm^2. Conflict initial condition is z(0)= z_a=3 cm.

Figure 10 is a simulation result.

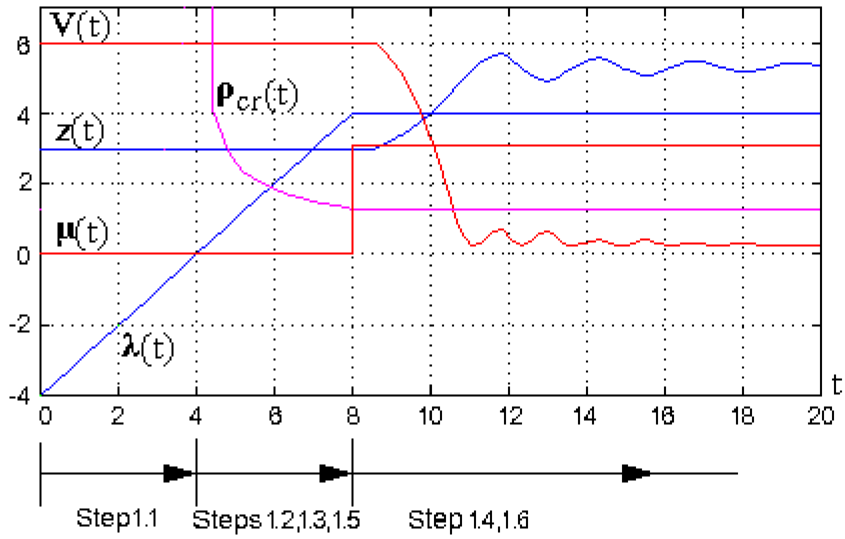

Figure 10

Stability margin of prototype falls during 0< t < 4 atu, but conflict coordinate z (t) is situated at stable equilibrium point. Overcoming psychological barrier of prototype is critical point **λ**(4) = 0. Conflict appears between technical contradictions TC1 and TC2. Conflict coordinate z (t) becomes an unstable equilibrium point. Conflict power **λ**(t) increases during 4 < t < 8 atu and becomes equal λ_2=4 cm^2 during $t \geq$ 8 atu. This power brings a steady-state value of coordinate $z = z_{vl}$ =5 cm. Conflict transient process begins during t = 8 atu. X-element comes up this time. Conflict Resolving Resource **μ**(t) grows to **μ**=3.1 cm^3 >μ_{cr}

instantly. Coordinate $z(t)$ increases smoothly, but potential function $V(t)$ decreases during $9 < t < 11$ atu. Transient process time depends on time constant T and time delay $\boldsymbol{\tau}$. Time delay causes damped oscillations of conflict coordinate. If delay is a zero, the oscillations are absent. There is a critical value $\boldsymbol{\tau}_{cr}$ ($\boldsymbol{\tau}_{cr}$=0.67 atu on the example), under which self-excited oscillations of coordinate $z(t)$ appear. Simultaneously potential function plot $V(t)$ have two frequency oscillations. If time delay is increasing, two and more frequencies oscillations are set up. Process becomes look like chaotic oscillations. Thinking of inventor escalates seeks the problem solving. Chaotic oscillation gives a powerful search effect. Obviously inventor can reduce its time delay before $\boldsymbol{\tau}<\boldsymbol{\tau}_{cr}$. Then chaotic oscillations are damped and solving is finding. Problem of delay control is required for the further study.

Conclusion

1. Mathematical model of technical contradiction is not an alternative to the algorithm of inventve problem solving. This model set up numerical relation the solving problem and ARIZ and can be used in simulated process on computer.
2. Dynamic contradiction control is refered to class of problems of artificial intelligence. Control actions (conflict power and volume) are given from outside, so control is programmed. The model of feedback control is a following problem.
3. Results of thiz paper can be used in physical contradiction models and other sections of TRIZ, for instance, in the laws of system evolution.

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