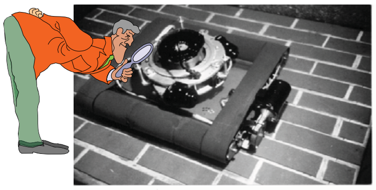
TRIZ シンポジウム 2005
The First TRIZ Symposium in Japan

TRIZ APPLICATION IN DEVELOPMENT OF CLIMBING ROBOTS



Valery Krasnoslobodtsev, Richard Langevin

© Technical Innovation Center Inc.
100 Barber Avenue
Worcester MA 01606 USA
Phone: +1 508-799-6700
Fax: +1 508-799-9944
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PRESENTATION *40 min*

1. INTRODUCTION: ABOUT THIS PROJECT

BEGINNING – 1986

FINISHING – 1998

BIRTH PLACE – Saint-Petersburg State Technical University and Intelmech Enterprise*

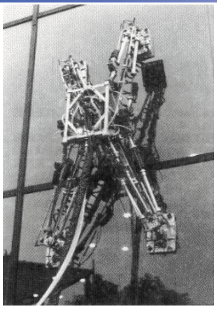
MAIN CUSTOMERS
- Ministry of Science and Technical Politics of Russian Federation (1991-1993)
- State Committee of Russian Federation on Higher Education (1993-1994)
- State Research Russian Centre of Robotics and Technical Cybernetic (1995-1998)
- Saint-Petersburg Subway (1995-1996)
- Saint-Petersburg Municipal Economy Academy (1986)
- Kiev Research-and-Production Corporation Electrical Household Device OBYTPRIBOR (1987-1988)
- Kalinin Nuclear Power Plant
- Portech Company, United Kingdom (1991-1992)
- University of Portsmouth, England (1992)

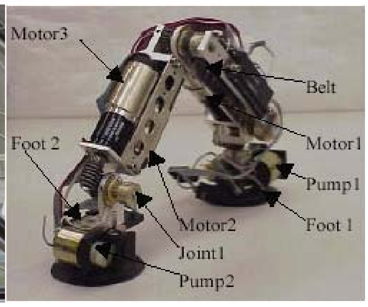
PUBLICATION AND PATENTS
- Scientific Book: V.Krasnoslobodtsev, V.Skvortsov. The adaptive pneumatic and vacuum grippers and supports of mobile robots. Publishing House of St Petersburg State Technical University, 1996
- 110 scientific publications including 55 Russian Patents and Author Certificates

NATIONAL AND INTERNATIONAL EXHIBITIONS
14 National Exhibitions and Conferences
5 International Conferences and Exhibitions including Japan (1990), United Kingdom (1992-1993), Finland (1993), Norway (1994), Spain (1997)

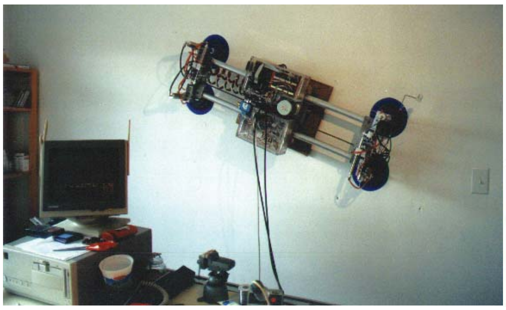
** Reference:*
http://www.spbstu.ru/mmf/KAFEDRY/Automat/Automat.htm

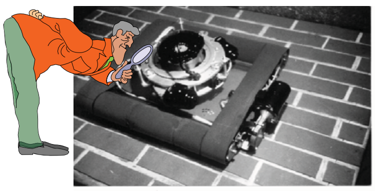
2. VACUUM CLIMBING ROBOT APPLICATION



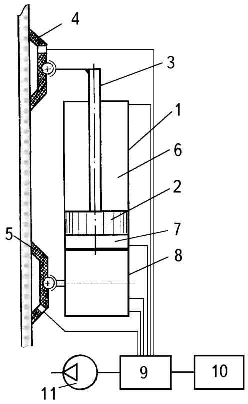
HOME APPLICATION - vacuum cleaning and washing of the window and walls
MUNICIPAL APPLICATION – cleaning of the glasses wall of the subway stations, airports, shops, offices, hospitals, hotels
SHIPBUILDING - cleaning of the ship's and submarine's bodies from the algae and mineral formations
NUCLEAR INDUSTRY - examining the inner structures of the nuclear reactors walls, diagnostic
MACHINE BUILDING - using like a vacuum manipulator with flexible structure, vacuum grippers
FIREMEN'S NEEDS - making of the robot-fireman may be the effective solution of the problem

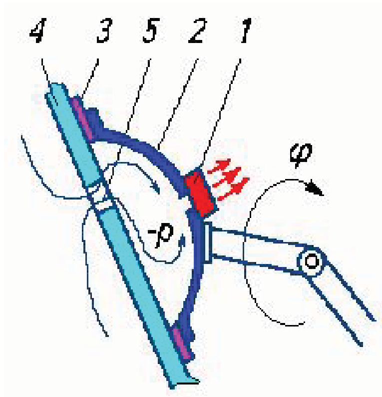


3. ARIZ DEVELOPMENT OF ADAPTIVE FEET

VACUUM FOOT PROBLEM STATEMENT





PROBLEM DESCRIPTION

The vacuum foot is most responsible element for safety of whole robot. The small-sized vacuum pump 1 (lower picture) is located on the foot body 2 which one has elastic seal 3. Seal 3 contacts with a glass surface 4. Vacuum is generated under foot and holds a robot.

If the glass surface doesn't have any defects then vacuum foot operates good. But if there is a defect 5 (crack, orifice, irregularity, etc.) in a glass surface then the efficiency of gripper is dropped because gripper is depressurized.

Typically, for compensation of the leaking high-power vacuum pump is used. But in this case the overall dimensions and robot weight are essentially increased.

MAIN TASK

It is necessary to save an existing vacuum method of the work and to propose a solution for a described above problem.

Part 1. PROBLEM ANALYSIS

1.1. MINI-PROBLEM

The climbing robot for washing window includes the vacuum pump, foot body, elastic seal, glass surface, crack on the surface, cylinder, rotary drive

TECHNICAL CONTRADICTION 1

If we use high-power vacuum foot in our design, it provides a good vacuum adhesion of the foot to a cracked glass surface but increases overall dimensions and mass of the vacuum pump

TECHNICAL CONTRADICTION 2

If we use low-power vacuum foot in our design, it does not increase dimensions and mass of the vacuum pump but it does not produce the required vacuum value under foot and adhesion during work with a cracked glass surface

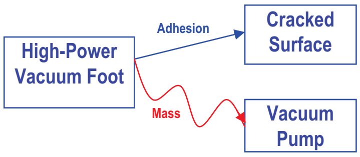
It is necessary with minimum modifications of existing system to provide reliable adhesion of the vacuum foot to the cracked glass surface and to keep the small dimensions and mass of the vacuum pump

Part 1. PROBLEM ANALYSIS
(continuation)

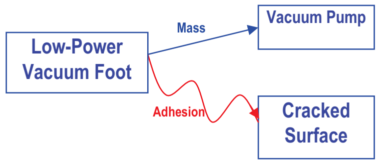
1.2. CONFLICTING PAIR
The product is a cracked glass surface and the vacuum pump
The tool is is the vacuum foot.

1.3. SCHEMES of CONFLICTS

Scheme of TC-1



Scheme of TC-2

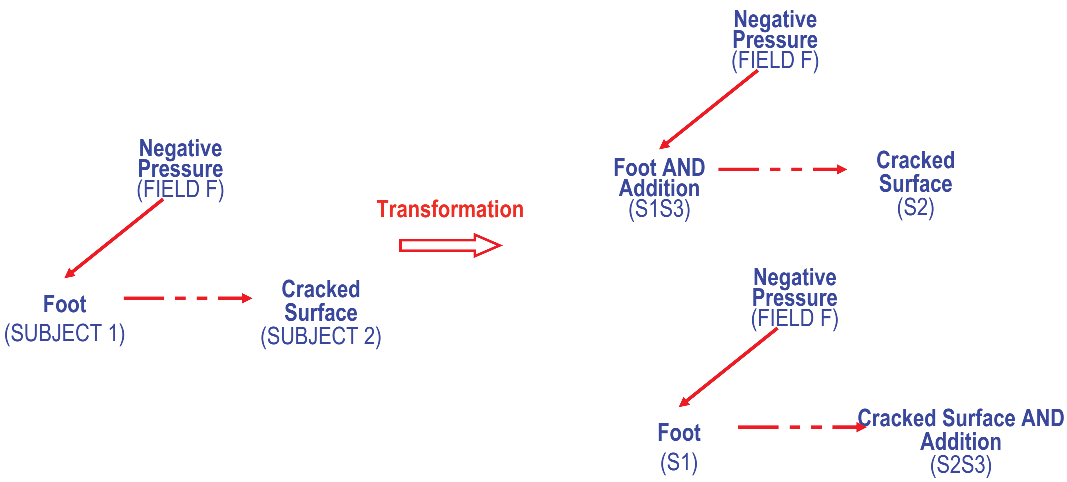


1.4. MAIN FUNCTION
As a main parameter was selected small overall dimensions and mass of applied vacuum pump and therefore use the low-power vacuum foot. Because we are planning to mainly use this robot in home conditions, which requires easy utilization. Therefore the scheme of the second conflict TC-2, for our further analysis, is selected.

1.5. AGGRAVATED VERSION OF THE CONTRADICTION
The very low negative pressure power practically does not increase sizes of gripper but also does not produce vacuum between gripper and cracked surface

1.6. MODEL OF A PROBLEM
A contradiction pair: a cracked glass surface is the product and foot with low-power vacuum is the tool
Formula of a conflict: the foot with low-vacuum power does not increase mass of pump and of robot (excellent!) but it does not produce adhesion between foot and cracked glass surface (bad!)
What should make entered X-element for a solution of this problem: X-element should provide vacuum adhesion between the foot and the cracked surface without increasing vacuum and the mass of foot and robot.

Part 1. PROBLEM ANALYSIS
(continuation)

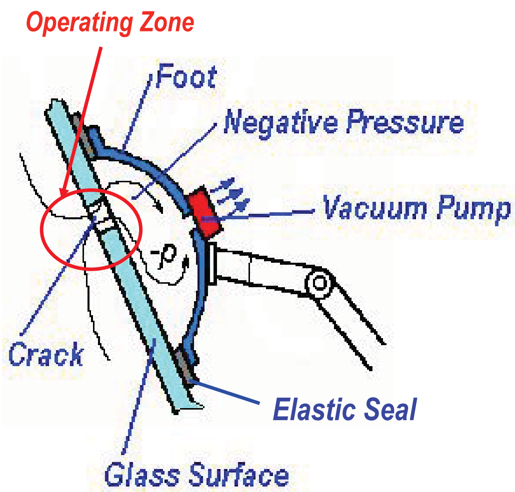


1.7. TO USE A SYSTEM OF THE STANDARDS TO PROBLEM MODEL SOLVING
Standard 1.1.2

Additional subject S3 is introduced inside foot (or Cracked Surface) to providing good vacuum adhesion

In this stage we get general answer for solving our problem – “Add SOMETHING (X-element) to the foot design OR to the cracked glass surface for solving this problem”.
The specific solutions will considered in the next part.

Part 2. ANALYSIS OF PROBLEM MODEL

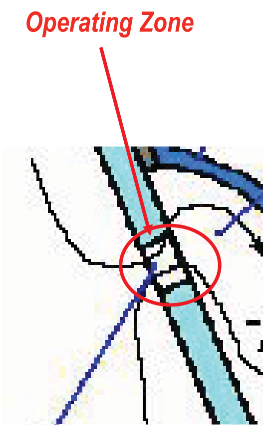


2.1. Determination of operating zone (OZ)
An operating zone is area near to a crack under foot and outside

2.2. Determination of operating time (OT)
It is the time of vacuum adhesion on a cracked glass surface by the vacuum foot

2.3. Substances and Fields Resources (SFR)
•Resources of the **vacuum foot** as tool: plastic body, elastic seal, negative pressure, normal force between seal and glass, frictional force
•Resources of the **glass surface** as product: glass surface, crack, air stream
•Resources of **supersystem and environment**: robot's equipment, ambient air, atmospheric pressure, gravitational and geomagnetic fields.

Part 3. IDEAL FINAL RESULT AND PHYSICAL CONTRADICTION



3.1. The Ideal Final Result (IFR)-1. *X-element* eliminates negative pressure decreasing under vacuum foot at the crack's zone (OZ) during vacuum suction (OT) without making the system more complex and without increasing the suction power and the mass of the system

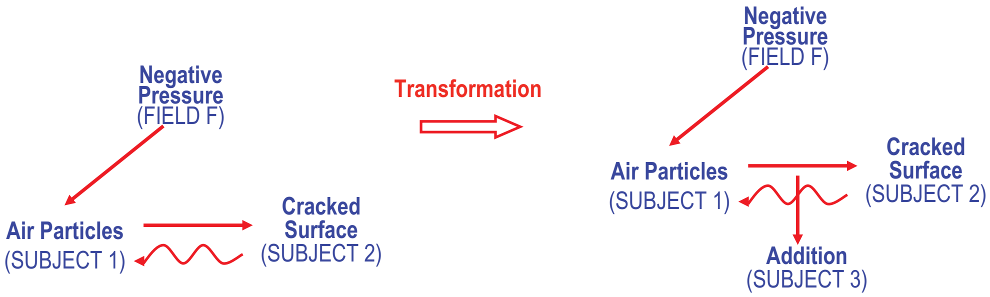
3.2. Intensified IFR-1: *It is impossible to enter into the system any new substances and fields,* and the X-element should be discovered from available resources. And so, the vacuum foot ITSELF (without using any foreign or new field and substances) eliminates negative pressure drop under vacuum foot in the crack's zone (OZ) during vacuum suction (OT) without making the system more complex and without increasing the suction power and the mass of the system

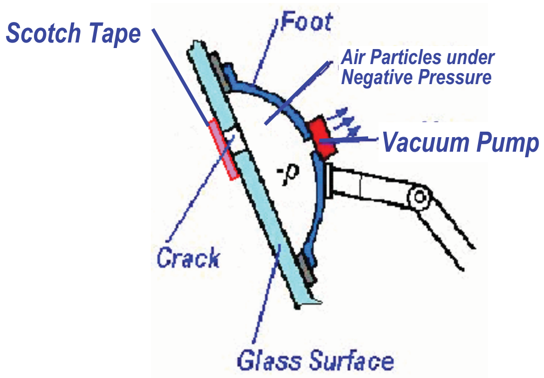
3.3. The Physical Contradiction on macrolevel (macroPhC): The operating zone under the vacuum foot near from crack in the glass surface during suction process should have negative pressure to provide vacuum adhesion between foot and surface and should have no negative pressure (should have atmospheric pressure) because of atmospheric air leaks under pressure differential through the crack and the vacuum foot

3.4. The Physical Contradiction on microlevel (microPhC): Air particles should not be under vacuum foot near to a crack during suction process for providing negative pressure AND should be because ambient air streams through the crack

3.5. IFR-2: The area under the foot along a crack and near (OZ) during adhesion process (OT) ITSELF provides opposite physical conditions (presence and absence of atmospheric air particles): atmospheric air particles of that flow through crack should be ITSELF transformed into "vacuum particles".

Part 3. IDEAL FINAL RESULT AND PHYSICAL CONTRADICTION





3.6. To check application of Standard Solutions to IFR-2.

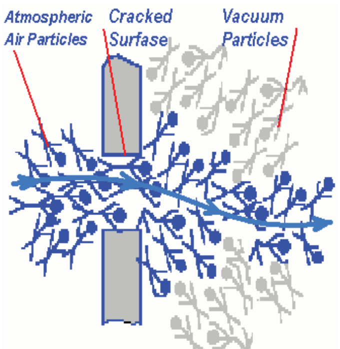
<u>Standard 1.2.1</u>

Additional subject S3 (free of charge) is introduced between air particles under negative pressure and cracked surface to providing good vacuum adhesion)

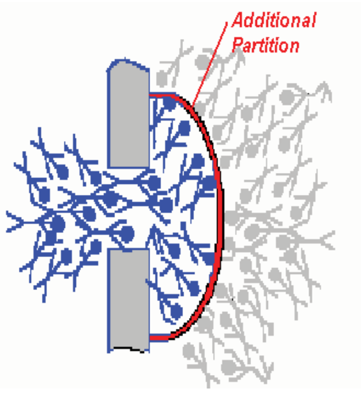
<u>SOLUTION 1</u>

To propose to use in advance inexpensive Scotch tape (or paper) closed crack and placed between vacuum foot and cracked surface. This tape may be placed in opposite side of cracked glass surface as shown in the picture

Part 4. MOBILIZATION AND UTILIZATION RESOURCES



Initial Conflict Scheme



Possible Conflict Solving Scheme

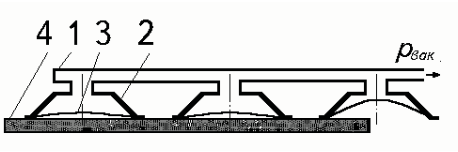
4.1. Application of "Small Smart People Modelling Method "

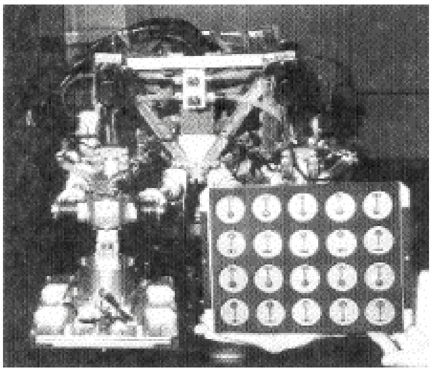
In the first scheme the conflict is represented: atmospheric air "blue small people" go through a crack in a surface and then displace vacuum "gray small people". Atmospheric air "blue small people" is much stronger than vacuum "gray small people". Therefore, "blue small people" press and displace "gray small people".

In the second scheme one of the variants for resolving of conflict is shown. There is no direct contact between two groups of people, therefore atmospheric air "blue small people" cannot directly interact with weak vacuum "gray small people".

This scheme gives us the idea - to use of a separating diaphragm and to make gripper as a multisectional design.

Part 4. USE OF RESOURCES





SOLUTION 2*

The new foot has body 1, designed as a frame. Within the frame are located numerous vacuum sectional mini-feet 2. Each mini-foot is supplied with elastic diaphragms 3 and are connected by common vacuum pump.

The system is installed on a surface 4 and a vacuum in the chambers of feet is formed. Under operation of vacuum, the elastic deformation of diaphragms occurs.

The diaphragm deformation leads to increasing of the volume between diaphragm 3 and surface 4, and therefore to making of vacuum. This vacuum leads to adhesion of the mini-feet to a glass surface.

The vacuum mini-feet that are not placed on a surface (on Fig 11 - on the right) or are located on a surface with a crack don't deactivate the rest of the system. These mini-feet don't have an influence on the other working vacuum mini-feet and are excluded automatically from work of the whole system.

Depressurization of other vacuum feet is not occurred and system continues successfully to work.

**** Reference:***
Patent SU1542543, 1990. Device for cleaning surfaces. Authors V.Krasnoslobodtsev, B.Brosalin, V.Savustjanov
http://v3.espacenet.com/origdoc?DB=EPODOC&IDX=SU1542543&F=0&QPN=SU1542543

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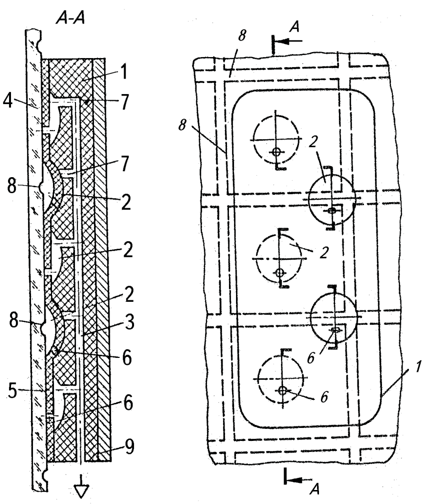
Part 4. USE OF RESOURCES



4.2. A method "Step Back From IFR": ***to represent future result with minimum deviations from IFR***

The realisation of this mental experiment leads to concept of making a small hole in the diaphragm in each section of the previous design of vacuum foot. We are getting a new construction of foot in Fig. 12, with new useful properties.

SOLUTION 3*

Using orifices in diaphragm provides new useful properties to the foot in comparison with previous design. The new foot can provide cleaning and evacuation dust particles through diaphragm orifices from the surface together with vacuum adhesion and so combines several functions at the same time.

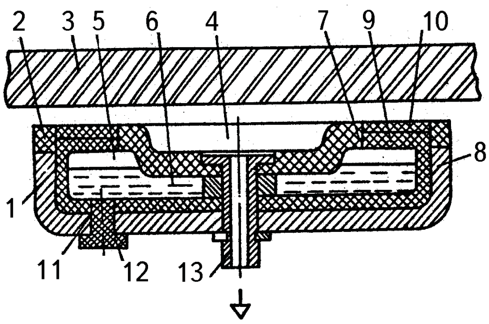
**** Reference:***
Vacuum Gripping Device. Patent SU1623937A1, 1991. Authors V. Krasnoslobodtsev, B. Brosalin
http://v3.espacenet.com/origdoc?DB=EPODOC&IDX=SU1623937&F=0&QPN=SU1623937

Part 4. USE OF RESOURCES

4.3. Using the mixture of resources: we are just marking the possibility of using an resource of air stream to produce a vacuum and will use this opportunity later

4.4. Application the mixture with a hollow (to use of porous structures: foam, air bubbles, etc.):

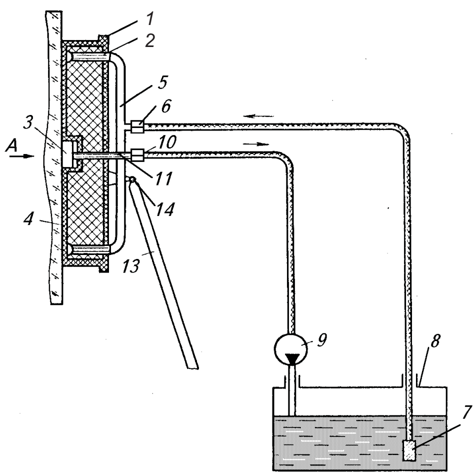
SOLUTION 4*

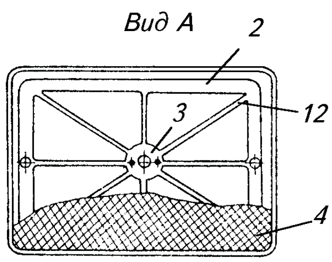


Mental experiments on this step leads to making of an elastic seal such as a sponge impregnated with a liquid, for example, water. The use of water allows considerably increasing “leakproofness” because the water closes micro-irregularities in a zone of a seal in contact with a surface. This property is a very important thing especially when the vacuum foot needs to move along a rough surface, for instance, a concrete wall. It was proposed for the new design of the foot (Fig. 13) and to use an inexpensive resource like water 6, inside vacuum foot 1. Sponge 9, on the working foot surface 10, supplies water. Using water greatly improves the contact area between foot 1 and rough surface 3 and eliminates the leakage between them. It is especially useful for working with concrete surfaces or other rough surface because water closes microasperities on the concrete surface and eliminates negative pressure reduction between vacuum foot and surface.

** Reference:*
Suction Grip. Patent SU1523515 A1, 1989. Authors V. Krasnoslobodtsev and B.Brosalin
http://v3.espacenet.com/origdoc?DB=EPODOC&IDX=SU1523515&F=0&QPN=SU1523515

Part 4. USE OF RESOURCES





SOLUTION 5*

It is proposed to use mixture with vacuum, and particularly, to move water 2 inside foot 1 by vacuum with help of pump 9 to provide cleaning and evacuation of dust particles from the surface together with vacuum.

Then the water is cleaned from dust particles by filter 7 and returned to cleaned surface 4.

Using the water is improved contact area between foot 1 and surface 4 and eliminated leakage between them.

Also water is used for cleaning smooth surface 4.

** Reference:*
Device for washing surfaces. Patent SU1588390A1, 1990. Authors V.Savustjanov, B.Brosalin, A.Volkov, V.Krasnoslobodtsev, V.Stastenko, V.Tkalich, M.Khenov
http://v3.espacenet.com/textdoc?DB=EPODOC&IDX=SU1588390&F=0

4.5. Application derived resources: *In our problem "hollow" is the vacuum so we already have applied and considered this before.*

4.6 and 4.7: *Have not been applied because additional electrical and magnet field applications seriously complicate existent system*

Part 5. INFORMATION FOUND APPLICATION

5.1. To apply the standards for a solution of inventive problems
5.2. To use analogies with solved before of non-standard problems on TRIZ
5.3. To use of methods of physical contradictions removal
5.4. To apply the Directory of physical effects and phenomena to removal PhC

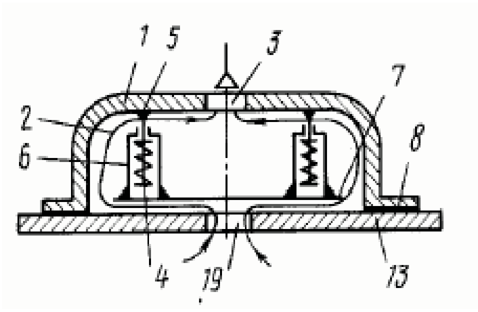
The using of procedures 5.1-5.4 allows to get the next results.

When we used the section of physics directory "Hydro- and gas-dynamics“ then we found Bernoulli's law which states: “where the stream velocity is higher the static pressure is lower”. For getting negative pressure near working surface it is necessary to accelerate an air stream. It can be made by various design methods. But we used approach to IFR: *"vacuum foot itself..."*

One from variants of vacuum foot is shown on the next slide.

Part 5. INFORMATION FOUND APPLICATION

SOLUTION 6*

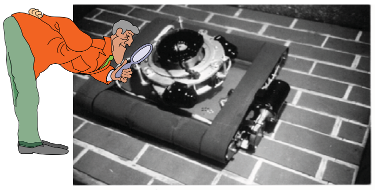


Through an hole 19 the air stream is formed. The direction of movement of this stream is shown on figure by arrows. As an area of a clearance between a flat surface 3 and flat disk 7 is least significant acceleration of an air stream occurs here. The increasing of a velocity leads to a pressure decrease in a clearance. The disk 7 and detail 13 are attracted. Clearance between a detail 13 and disk 7 decreases more and more and air stream velocity increases more and more. Finally the stabilisation of a clearance and level of negative pressure between the disk 7 and surface 13 are occurred. Thus vacuum foot is fixed on cracked surface 13.

The level of negative pressure between the disk 7 and surface 13 can be adjusted by a modification of productivity of the vacuum pump, area of a clearance, square of the disk 7, and also depends on a sectional area of an orifice 19.

** Reference:*
***Vacuum grip.** Patent RU2043193C1, 15/00, 1995. Authors V.Krasnoslobodtsev, A.Sergienko*
http://v3.espacenet.com/origdoc?DB=EPODOC&IDX=RU2043193&F=0&QPN=RU2043193

The described above technical solutions satisfy both parts of contradictions . The proposals are approximated to ideal solution because foot itself provides resolving indicated contradiction by using just internal resources with minimal modification of the design.



4. TRIZ EVOLUTION TRENDS

DEVELOPMENT OF ROBOT DESIGN

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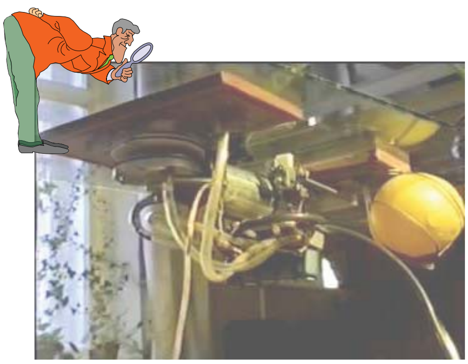
TRIZ TRENDS OF EVOLUTION

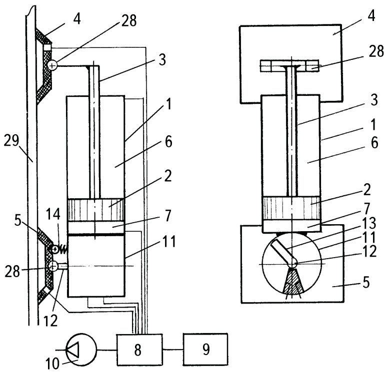


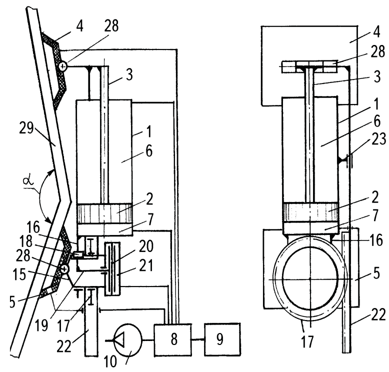
1. Completeness and Life Cycle of Technical Systems
2. Energetic Conductivity of System
3. Transition to Synchronization (matching/mismatching)
4. Increasing of System Ideality
5. Uneven development of subsystems
6. Transition to a super- or subsystem’s levels (Mono-Bi-Poly-Systems)

6,a. Dynamization

7. Transition to microlevel using energy fields
8. Increasing the system S-Field development

PROBLEM SOLVING 1*





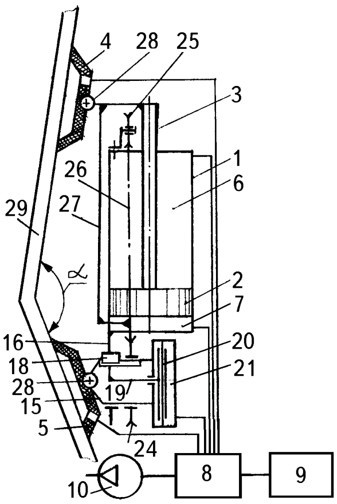
Application of TRIZ Ideality Principle. The vacuum wall-climbing robot with two pneumatic drive. Design version 1

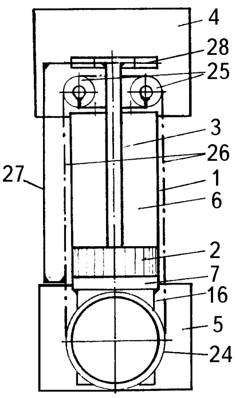
Application of TRIZ Ideality Principle. The vacuum wall-climbing robot with one pneumatic drive. Design version 2

Reference:

Patent on claim № RU 4804846/11-034703, IC B62D 57/00, 1993. The system for moving on the arbitrary oriented surfaces in space. V.Krasnoslobodtsev, B.Brosalin, L.Sungurova, V.Djachenko, A.Volkov

PROBLEM SOLVING 2*
PROBLEM SOLVING 3*





Application of TRIZ Ideality Principle. The vacuum wall-climbing robot with flexible linkage between linear drive and vacuum clutch. Design version 3

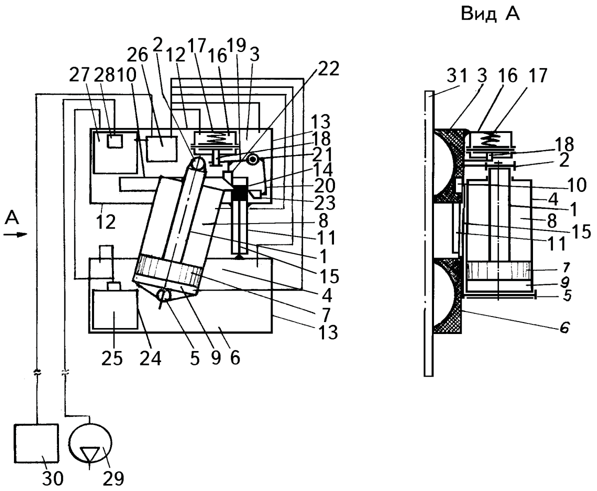
Using the rack in the construction shown in fig.17 leads to increasing the weight and overall dimensions of the robot. Could we increase ideality of robot once again by elimination of this rack while keeping its driving function? It was proposed to make “flexible rack”, which leads to concept of design with application instead of a rack with a belt-drive, chain-drive or cord linkage 26 (fig.18). As a result of weight and dimensions of the robot are improved

Reference:

Patent on claim № RU 4804846/11-034703, IC B62D 57/00, 1993. ***The system for moving on the arbitrary oriented surfaces in space.*** *V.Krasnoslobodtsev, B.Brosalin, L.Sungurova, V.Djachenko, A.Volkov*

TRIZ IDEALITY TREND APPLICATION

PROBLEM SOLVING 4*



Application of TRIZ Ideality Principle.

The vacuum wall-climbing robot with one linear drive and two-coordinate motion. Design version 4

Is it proposed to use vacuum double-foot wall climbing robot with just one cylinder and two-coordinate drive for realization motion in any direction.

So there is only one cylinder that provided functions of the two cylinders.

Reference:

Surface cleaning apparatus. Patent RU2080812, 1994. Authors V.Krasnoslobodtsev, G.Bibikova
http://v3.espacenet.com/textdoc?DB=EPODOC&IDX=RU2080812&F=0

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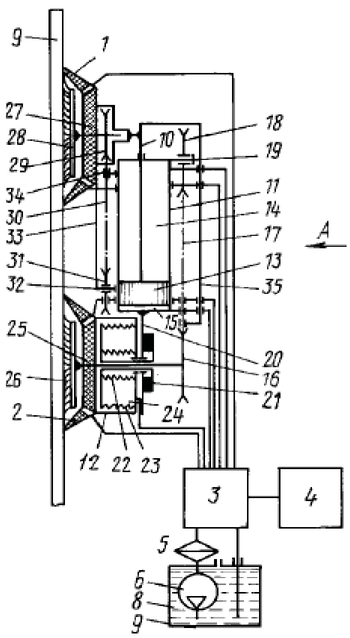
TRIZ IDEALITY TREND APPLICATION

PROBLEM SOLVING 5*



Application of TRIZ Ideality Principle.

The vacuum wall-climbing robot with multifunctional feet. Design version 5

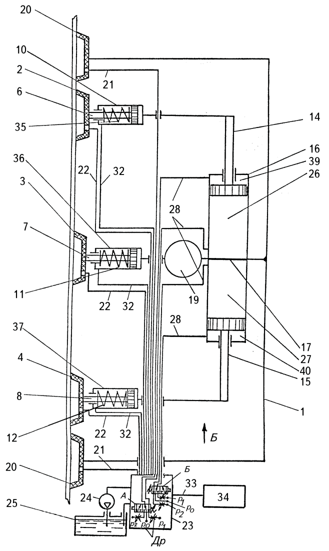
It was proposed to improve the cleaning robot's function by using brushes 26 and 28 under vacuum feet 2 and 1. Cleaning rotation of these brushes is curried out from linear drive 11 without the application of additional motors. Thus, cleaning parameters of the robot are improved with minimal changes in the design. The robot's feet carry out several functions simultaneously: providing of vacuum keeping for robot and motion on the surface; circulation of washing solution on surface; additional mechanical cleaning of the surface with brushes using. So we use this way for increasing of robot's ideality by transferring of additional functions to vacuum foot.

Reference:

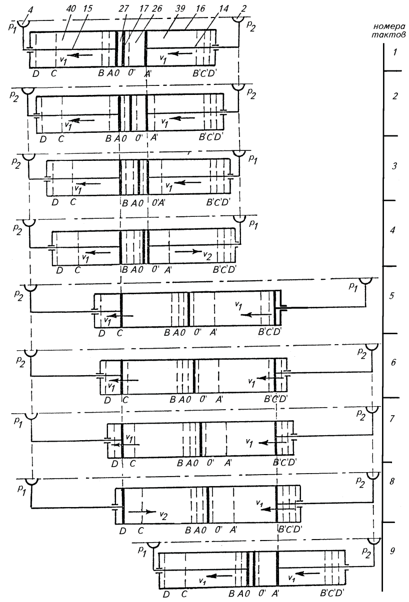
Apparatus for treating continuous surface. Patent RU2080811, 1997. Authors V. Krasnoslobodtsev
http://v3.espacenet.com/textdoc?DB=EPODOC&IDX=RU2080811&F=0

UTILIZATION OF MONO-BI-POLY EVOLUTION TREND

PROBLEM SOLVING 6*



The scheme of the bi-cylinder climbing robot with the linear vacuum drive and with non-stop moving



The cyclogram of movement of the bi-cylinder climbing robot with linear discrete vacuum drive and non-stop moving

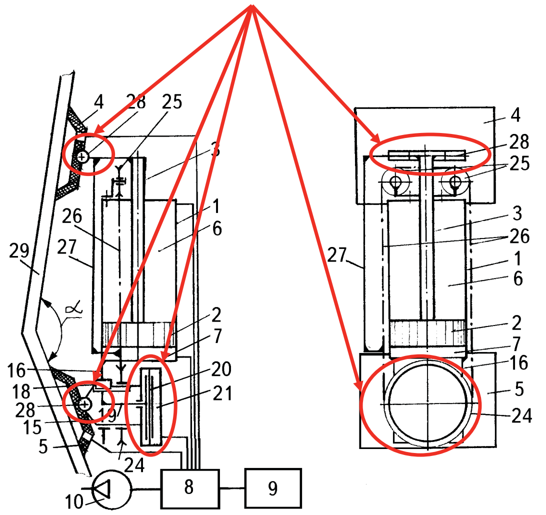
Reference:

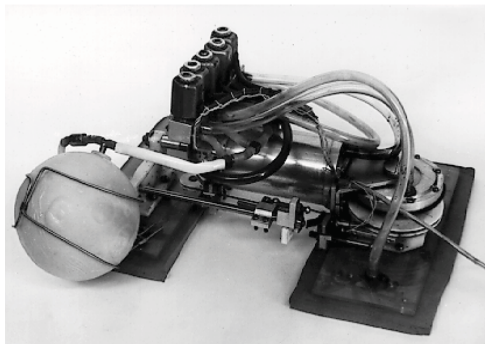
*Patent № SU 1785650 A1, IC A47L 01/08, 1992.*The system for cleaning of smooth surfaces. A.Dzyubin, V.Krasnoslobodtsev

UTILIZATION OF DINAMIZATION TREND

PROBLEM SOLVING 7*

Additional Joints





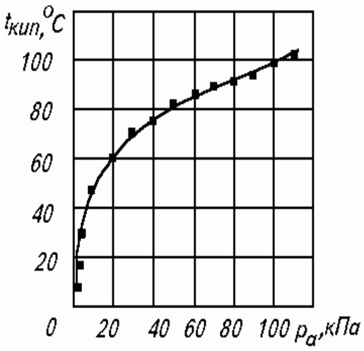
It is proposed to apply TRIZ trend of system dynamism and to use additional joins into the robot for increasing performances.
This robot can be used not only for the smooth surfaces and also for cleaning of profiled surfaces.

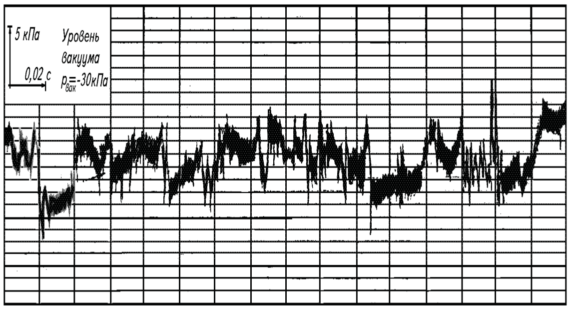
Reference:

*Patent on claim № RU 4804846/11-034703, IC B62D 57/00, 1993.*The system for moving on the arbitrary oriented surfaces in space. V.Krasnoslobodtsev, B.Brosalin, L.Sungurova, V.Djachenko, A.Volkov

TRANSITION TO MICROLEVEL USING ENERGY FIELDS

PROBLEM SOLVING 8





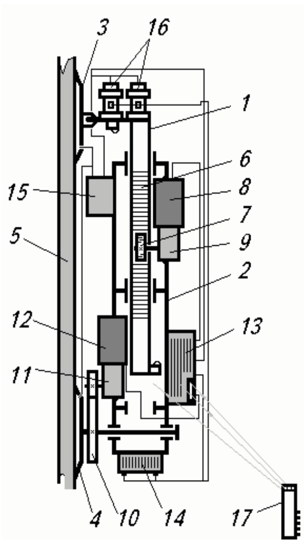
Correlation between boiling temperature
cavitation

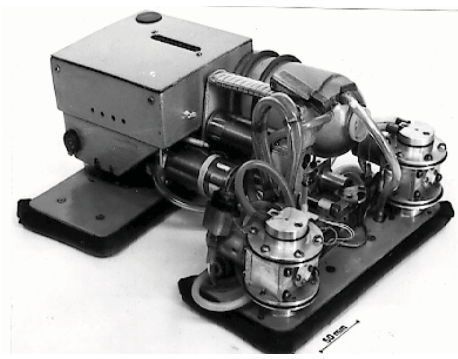
Experimental oscillogram of pressure change under
and ambient pressure for water

It is proposed to clean surface on the microlevel and use cavitation phenomenon. Cavitation under vacuum foot produces cavitation bubbles. The collapsing bubbles erode the dust and dirt on the cleaned surface and then liquid flow takes dirt away from surface. For protection foot's surface from cavitation erosion in the passages, a special plastic coating is used.

UTILIZATION OF S-FIELD DEVELOPMENT TREND

PROBLEM SOLVING 9





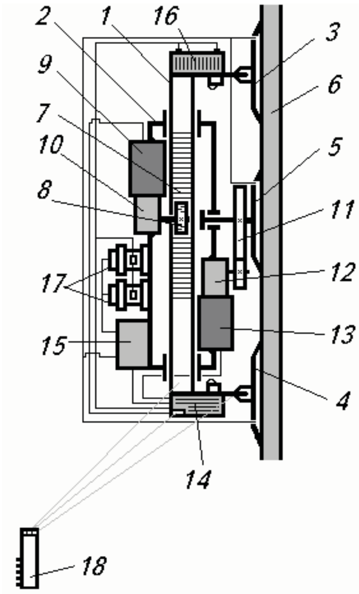
Scheme of the two-feet climbing robot with electromechanical step-by-step drive

General view of the two-feet climbing robot

In accordance with the trend of increasing the S-Field involvement, it was proposed to use transition from mechanical (pneumatic/vacuum) drive to electromechanical drive by using electric motors. This transition was very promising and helpful because it gave the possibility to make an autonomous robot module without any connecting lines.

UTILIZATION OF S-FIELD DEVELOPMENT TREND

PROBLEM SOLVING 10

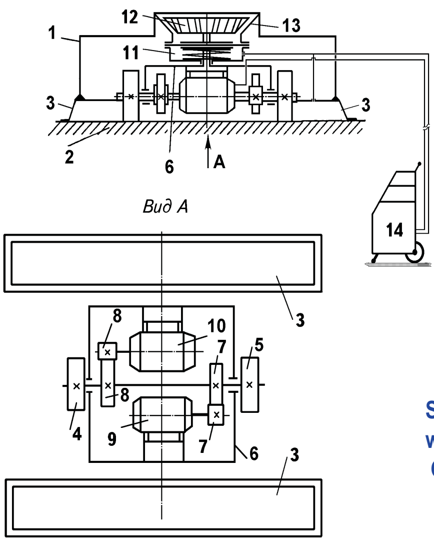


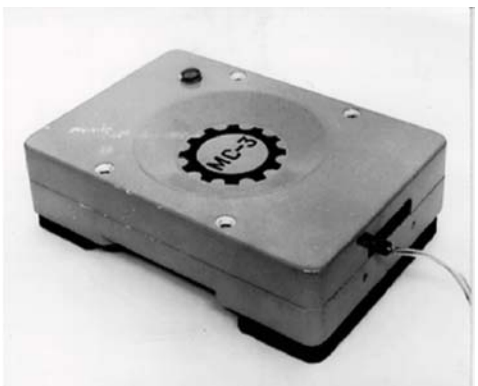
Scheme of the climbing robot with segmenting foot and electromechanical step-by-step drive.
General view of the three-feet climbing robot

This problem is related to improvement of the robot's motion parameters. By dividing or segmenting one of the vacuum feet gave new property for stable and precise movement of the robot along the horizontal line without deviation on the vertical surface. Just make note that segmentation is increasing in the degree of dispersion of substance and correlates with S-Field development trends.

UTILIZATION OF S-FIELD DEVELOPMENT TREND

PROBLEM SOLVING 11



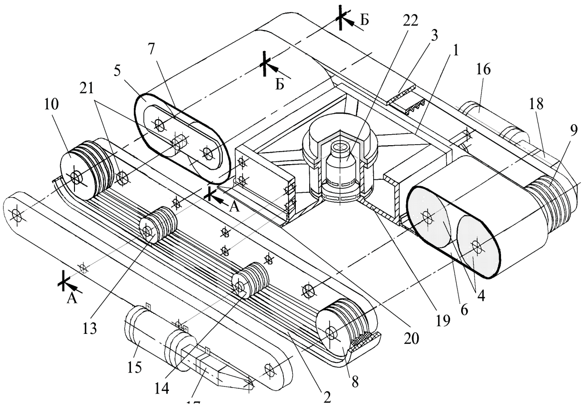


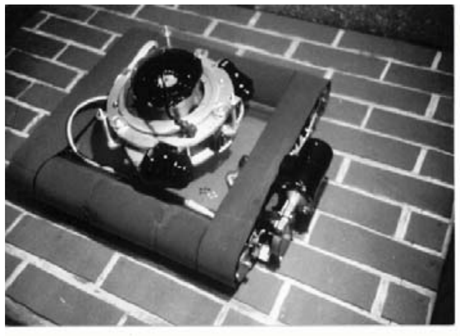
Scheme of wall-climbing robot with electromechanical non-stop wheel drive
General view of the wheel wall-climbing robot

The problem solving is devoted to increasing of the responsiveness of the robot or it's controllability and manoeuvrability. The wheel robot has non-stop movement and increased controllability and manoeuvrability. The robot can be used for "dry" work including painting, welding and diagnostics. However, wheel drive cannot force a big load. Under that load, the wheels slip on the working surface and the robot cannot move.

UTILIZATION OF S-FIELD DEVELOPMENT TREND

PROBLEM SOLVING 12





Scheme of the caterpillar climbing robot with electromechanical drive
General view of the caterpillar climbing robot

Caterpillar robot design resolves physical contradiction: “The friction between a foot surface and working surface should be big for stable work of the robot without occasional sliding and should not be big (should be small) in order to robot can easy move”.

All components of the vacuum foot are with rolling friction without counteraction to motion like in previous wheel design. Increasing the vacuum under the caterpillar-foot leads to improving of the vacuum adhesion with working surface and the elimination of the robot’s sliding under a load, for instance. The caterpillar vacuum robot successfully combines reliable vacuum adhesion even on brick surface with non-stop motion principle and good controllability and manoeuvrability of the wheel robot.

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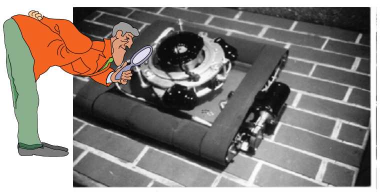

5. VIDEO OF CLIMBING ROBOTS.

CONCLUSION