

Containment ring problem (Impeller burst)

IWB Case study

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Editor's note: This paper shows the application of the Ideation Workbench Method to the case that was presented in the September 2000, issue of the TRIZ Journal.

Innovation Situation Questionnaire

1. Brief description of the problem

The engineered system, which is designed to contain the fragments resulting from an impeller burst of a maximum-speed fan, consists of the following: a fan, fan shroud (which controls the direction of the air stream), and an armor-steel containment ring. The problem to be solved is that the ring is too heavy and must be reduced in weight by 50%.

2. Information about the system

2.1 System name

The following systemic levels might be considered:

- Containment ring
- Fan
- Air conditioning system
- Aircraft
- Testing of ring

For the ring, the problem is as follows: the ring must be strong to withstand the impact of the impeller fragments, and the ring should not be heavy.

For the fan, the problem is as follows: the impeller can burst, but fragments should not fly away.

For the air-conditioning system, the problem is as follows: the impeller can be broken, but the air should be conditioned.

For the aircraft, the problem is as follows: the impeller can burst, but neither people nor equipment should be harmed.

For testing the ring, the problem is as follows: the ring's ability to capture flying fragments should be tested, but it is difficult to move the heavy ring back and forth.

Idea # 1

Make the ring as an assembly made of light-weight parts that are easy to move for testing purposes.

We can influence two systemic levels: the ring and the fan assembly. Let's select the fan assembly as the system to be considered.

2.2 System structure

The fan assembly consists of the following elements:

- fan
- motor
- shaft
- motor support
- containment ring
- connectors or support to keep the ring

2.3 Functioning of the system

The primary useful function of the fan is to supply (move) air for the air conditioning system.

The fan rotates quickly and moves air. The air is conditioned so that the aircraft cabin can be supplied with conditioned air.

2.4 System environment

Other parts of the air conditioning system:

- pipes
- heat exchanger
- airflow distributors

Other systems located nearby:

- aircraft covering
- equipment

Other system interacting with the fan and air conditioning system:

- electrical power supply
- air supply
- exhaust air removal
- vibration dampers

Conditions around the system: indoor conditions

3. Information about the problem situation

3.1 Problem that should be resolved

Reduce the weight of the ring by 50%.

The primary harmful function of the given system (the fan assembly) is that impeller fragments fly away if the impeller bursts.

3.2 Mechanism causing the problem

The containment ring must be strong to contain the flying fragments – for this reason the ring is thick and, as a result, heavy.

The cause of an impeller burst is as follows: Rotation of the fan results in centrifugal forces that "pull" the parts of the impeller. The strength of the impeller material can be compromised by material defects and fatigue. As a result, the impeller can burst, causing the impeller fragments to fly off. Due to the high speed at which the fan rotates, the flying fragments carry high energy and can harm people and other parts of the aircraft.

2.3 Undesired consequences of unresolved problem

The high weight of the ring makes it difficult to carry out the routine tests required by the FAA.

The "dead weight" of the aircraft equipment is also high.

If the weight problem is resolved at the expense of the ring's strength, the result will be inadequate protection from the flying impeller fragments, which in turn can result in death and/or damage.

2.4 History of the problem

The increased requirements for conditioning the air are met using a higher velocity airflow, but this means that the rotational speed of the fan increases. As a result, an impeller burst becomes more probable and the danger from the flying fragments increases. Because the energy of the flying fragments is increased, the ring must be stronger. As a result, the ring is heavier.

Known attempts to reduce the ring thickness resulted in a reduction in strength.

Idea # 2

Provide high airflow with low rotational speed of the fan. Perhaps utilize several slow fans instead of one that rotates quickly

2.5 Other systems in which a similar problem exists

Similar problems exist in many other areas where weight and mechanical strength are critical issues, as well as other systems for protection against flying parts. We do not have any information about how these problems have been addressed.

2.6 Other problems to be solved

Use an alternative method to contain the fragments.

Make the impeller unbreakable.

Others (see the problems on different systemic levels in the beginning of the ISQ).

3. Ideal vision of solution

No containment ring is necessary.

An impeller burst is no longer possible.

4. Available resources

Substance resources

- Material of containment ring
- Material of fan impeller
- Other objects around
- Airflow

Field resources

- Mechanical forces
- Airflow energy
- Electrical energy
- Magnetic field (motor)

Space resources

- Space inside the ring
- Space outside the ring

Time resources

- Time during which the fan is not operating
- Time when the fan is operating
- Time before the impeller bursts
- Time after the impeller bursts

Informational resources: No special resources

Functional resources

- Rotation

5. Allowable changes to the system

- Drastic changes are allowed.
- Any reduction in strength is unacceptable.

6. Criteria for selecting solution concepts

- Weight reduction of at least 30%
- Cost increase of no more than 5%
- About two weeks for new design
- One year for implementation

7. Description of the company business environment

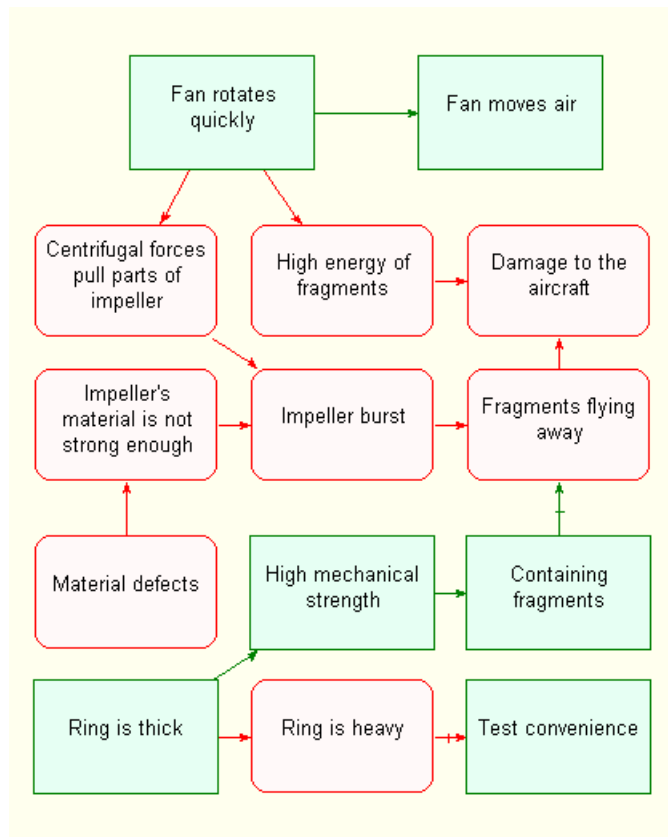
(Withheld)

8. Project data

(Withheld)

Problem Formulation

The Diagram



Basic Directions for Innovations:

Problem statement	Priority code	Direction	Preliminary ideas
1. Find a way to eliminate, reduce, or	1	Reduce	

prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).		weight or density Change the structure	
2. Find an alternative way to obtain [the] (Ring is thick) that offers the following: provides or enhances [the] (High mechanical strength), does not cause [the] (Ring is heavy).	1	Reduce weight or density Change the structure	
3. Try to resolve the following contradiction: The useful factor [the] (Ring is thick) should be in place in order to provide or enhance [the] (High mechanical strength), and should not exist in order to avoid [the] (Ring is heavy).	1	Resolve contradiction related to the ring thickness	
4. Find an alternative way to obtain [the] (High mechanical strength) that offers the following: provides or enhances [the] (Containing fragments), does not require [the] (Ring is thick).	1	Improve mechanical strength	
5. Find an alternative way to obtain [the] (Containing fragments) that offers the following: eliminates, reduces, or prevents [the] (Fragments flying away), does not require [the] (High mechanical strength).	2	Contain fragments with the weak ring	Idea # 3: Utilize a "weak" ring that will absorb energy as it is destroyed
6. Find a way to eliminate, reduce, or prevent [the] (Fragments flying away) in order to avoid [the] (Damage to the aircraft), under the conditions of [the] (Impeller burst).	2	Stop fragments from flying	
7. Find a way to eliminate, reduce, or prevent [the] (Impeller burst) in order to avoid [the] (Fragments flying away), under the conditions of [the] (Centrifugal forces pull parts of impeller) and (Impeller's material is not strong enough).	3	Prevent the burst	
8. Find a way to eliminate, reduce, or prevent [the] (Centrifugal forces pull parts of impeller) in order to avoid [the] (Impeller burst), under the conditions of [the] (Fan rotates quickly).	3	Counteract centrifugal forces	
9. Find an alternative way to obtain [the] (Fan rotates quickly) that offers the following: provides or enhances [the] (Fan moves air), does not cause [the] (Centrifugal forces pull parts of impeller)	Out of scope	Alternative fan rotation	

and (High energy of fragments).			
10. Try to resolve the following contradiction: The useful factor [the] (Fan rotates quickly) should be in place in order to provide or enhance [the] (Fan moves air), and should not exist in order to avoid [the] (Centrifugal forces pull parts of impeller) and (High energy of fragments).	Out of scope	Resolve contradiction related to the speed of fan rotation	
11. Consider transitioning to the next generation of the system that will provide [the] (Fan moves air) in a more effective way and/or will be free of existing problems.	Out of scope		
12. Find an alternative way to obtain [the] (Fan moves air) that does not require [the] (Fan rotates quickly).	Out of scope	Move air without rotation	
13. Find a way to eliminate, reduce, or prevent [the] (Damage to the aircraft) under the conditions of [the] (Fragments flying away) and (High energy of fragments).	Out of scope	Protect aircraft from fragments	
14. Consider transitioning to the next generation of the system that will provide [the] (Test convenience) in a more effective way and/or will be free of existing problems.	Out of scope		
15. Find an alternative way to obtain [the] (Test convenience) that is not influenced by [the] (Ring is heavy).	1	Improve test convenience	Idea # 4: Perform testing without removing the ring
16. Find a way to eliminate, reduce, or prevent [the] (High energy of fragments) in order to avoid [the] (Damage to the aircraft), under the conditions of [the] (Fan rotates quickly).	1	Reduce energy of fragments	Idea # 5: Reduce the mass of the fragments to reduce damage
17. Find a way to eliminate, reduce, or prevent [the] (Material defects) in order to avoid [the] (Impeller's material is not strong enough).	3	Screen material	
18. Find a way to eliminate, reduce, or prevent [the] (Impeller's material is not strong enough) in order to avoid [the] (Impeller burst), under the conditions of [the] (Material defects).	3	Improve strength of impeller	

Prioritize Directions and Generate Preliminary Ideas

The following preliminary ideas have been resulted from the direct analysis of the basic Directions:

3. Utilize a "weak" ring that will absorb energy as it is destroyed
4. Perform testing without removing the ring
5. Reduce the mass of the fragments to reduce damage

Directions selected for further considerations

Selected Basic Directions	Selected Refined Directions or Undesired factor
1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).	Reduce weight
4. Find an alternative way to obtain [the] (High mechanical strength) that offers the following: provides or enhances [the] (Containing fragments), does not require [the] (Ring is thick).	4.1. Improve the useful factor (High mechanical strength).
3. Try to resolve the following contradiction: The useful factor [the] (Ring is thick) should be in place in order to provide or enhance [the] (High mechanical strength), and should not exist in order to avoid [the] (Ring is heavy).	3.1. Apply separation principles to satisfy contradictory requirements related to [the] (Ring is thick).
5. Find an alternative way to obtain [the] (Containing fragments) that offers the following: eliminates, reduces, or prevents [the] (Fragments flying away), does not require [the] (High mechanical strength).	5.3. Increase effectiveness of the useful action of [the] (Containing fragments).
7. Find a way to eliminate, reduce, or prevent [the] (Impeller burst) in order to avoid [the] (Fragments flying away), under the conditions of [the] (Centrifugal forces pull parts of impeller) and (Impeller's material is not strong enough).	Protect from fire or explosion
	Reduce deformation, displacement, shock, vibration or destruction
15. Find an alternative way to obtain [the] (Test convenience) that is not influenced by [the] (Ring is heavy).	15.1. Improve the useful factor (Test convenience).

Direction1: Reduce weight

The screenshot shows the Innovation WorkBench interface. The left panel, titled "Prioritize Directions", lists 19 directions for further consideration. The right panel, titled "Reduce weight to save material", provides recommendations for operators to save material.

Prioritize Directions
1. Directions selected for further consideration

- » 1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).
 - 1.1. Isolate the system or its part from the harmful effect of [the] (Ring is heavy).
 - 1.2. Counteract the harmful effect of [the] (Ring is heavy).
 - 1.3. Impact on the harmful action of [the] (Ring is heavy).
 - 1.4. Reduce sensitivity of the system or its part to the harmful effect of [the] (Ring is heavy).
 - 1.5. Eliminate the cause of the undesired action of [the] (Ring is heavy).
 - 1.6. Reduce the harmful results produced by [the] (Ring is heavy).
 - 1.7. Apply universal Operators to reduce the undesired factor (Ring is heavy).
 - 1.8. Consider resources to reduce the undesired factor (Ring is heavy).
 - 1.9. Try to benefit from the undesired factor (Ring is heavy).

Reduce weight to save material
To save material, consider the following recommendations (Operators):

- Abandon symmetry
- Reduce the weight of individual parts
- Strengthen individual parts
- Apply inflatable constructions

Operator: Abandon symmetry

The screenshot shows the Innovation WorkBench interface with the "Abandon symmetry" operator selected. The right panel provides a definition and illustrations of the operator. A smaller window titled "Asymmetrical mounts" is also visible, showing images of motor mounts and their design considerations.

Abandon symmetry
If an object is symmetrical, consider reducing its weight by abandoning the symmetry – for example, by excluding a part of the object that does not bear the main load.

Illustrations:
★ [Asymmetrical mounts](#)
★ [Economical ski pole baskets](#)

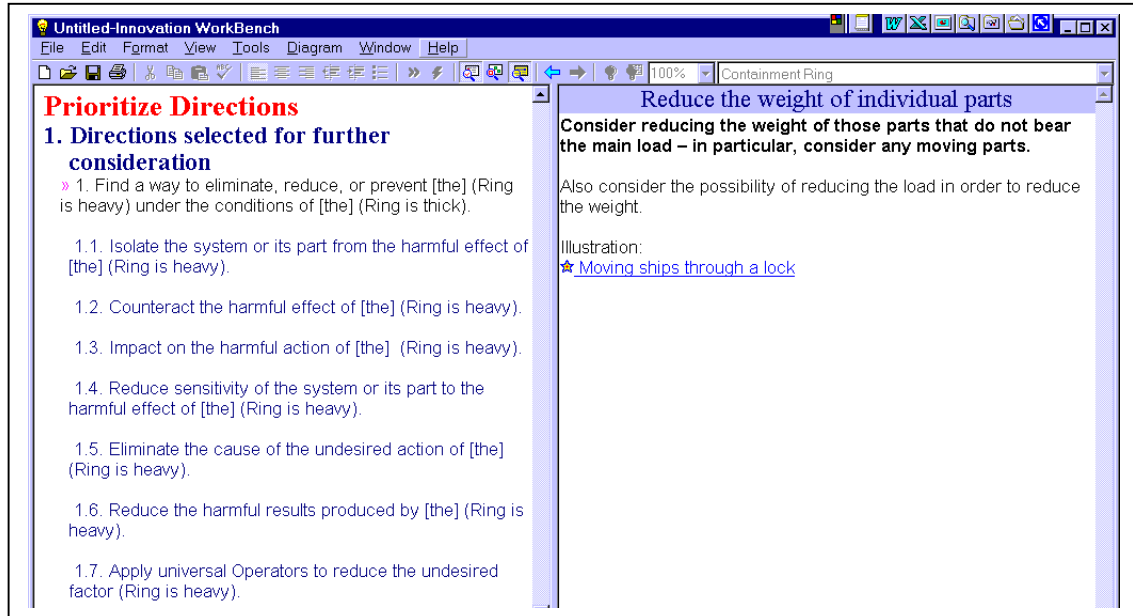
Asymmetrical mounts
For aesthetic reasons, motor and generator mounts are often designed with symmetrical shapes. Because the machines rotate, however, the load on the mounts is actually asymmetrical.

To reduce weight and conserve material, mounts for non-reversible units should be designed to support only the loads they must actually bear.

Idea # 6

Vary the thickness of the ring tube. Reduce the thickness where permissible.

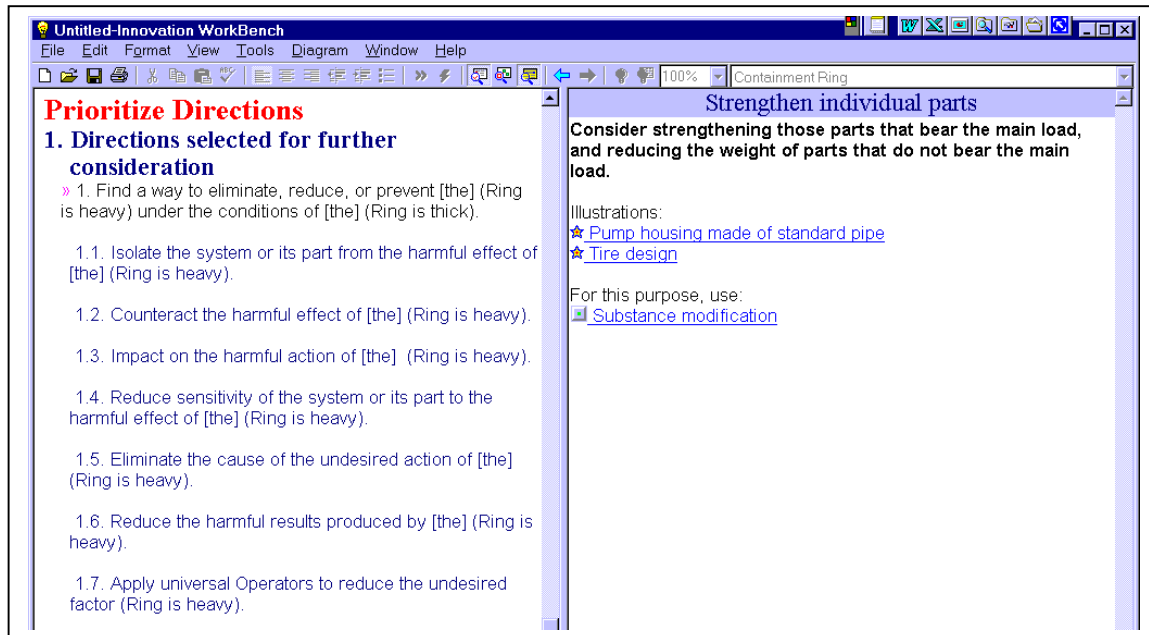
Operator: Reduce the weight of individual parts



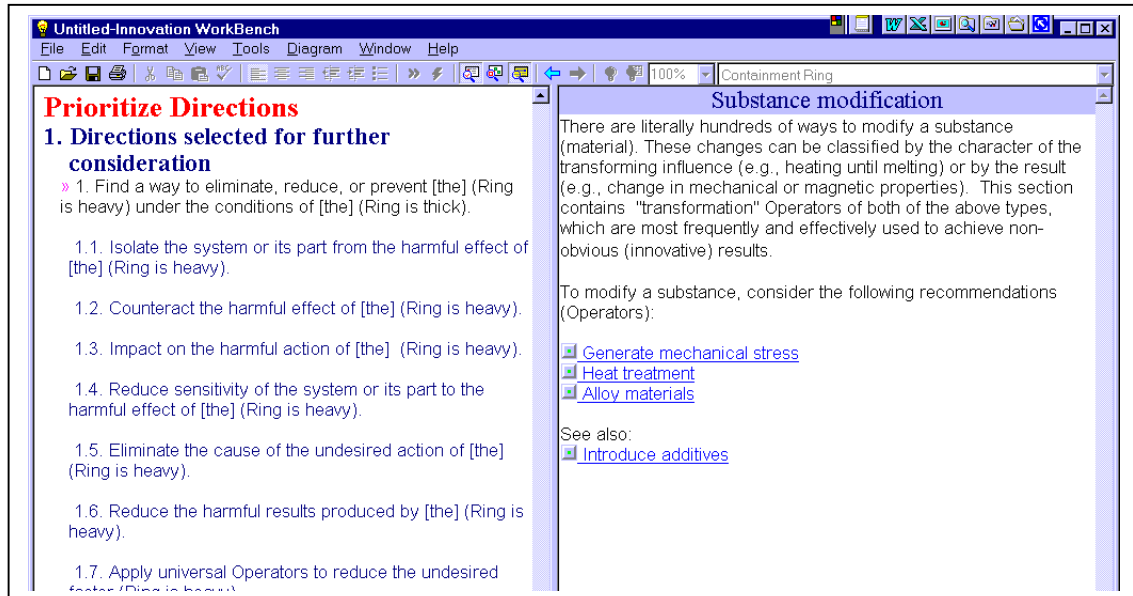
Idea # 5a

Reduce the energy of fragments by reducing their weight (i.e. help the impeller break into smaller pieces). That will allow the ring to be made less strong and thus lighter.

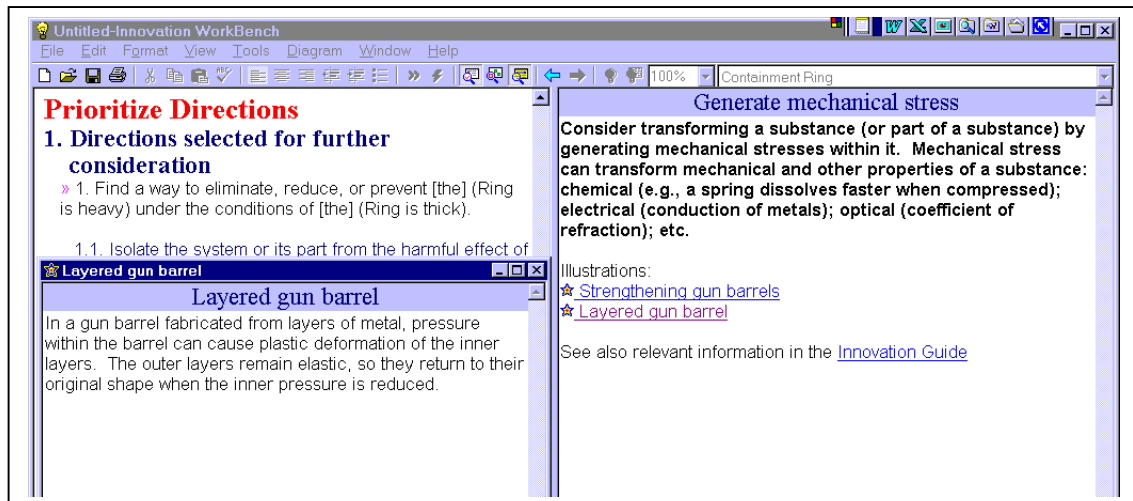
Operator: Strengthen individual parts



Auxiliary Operator: Substance modification



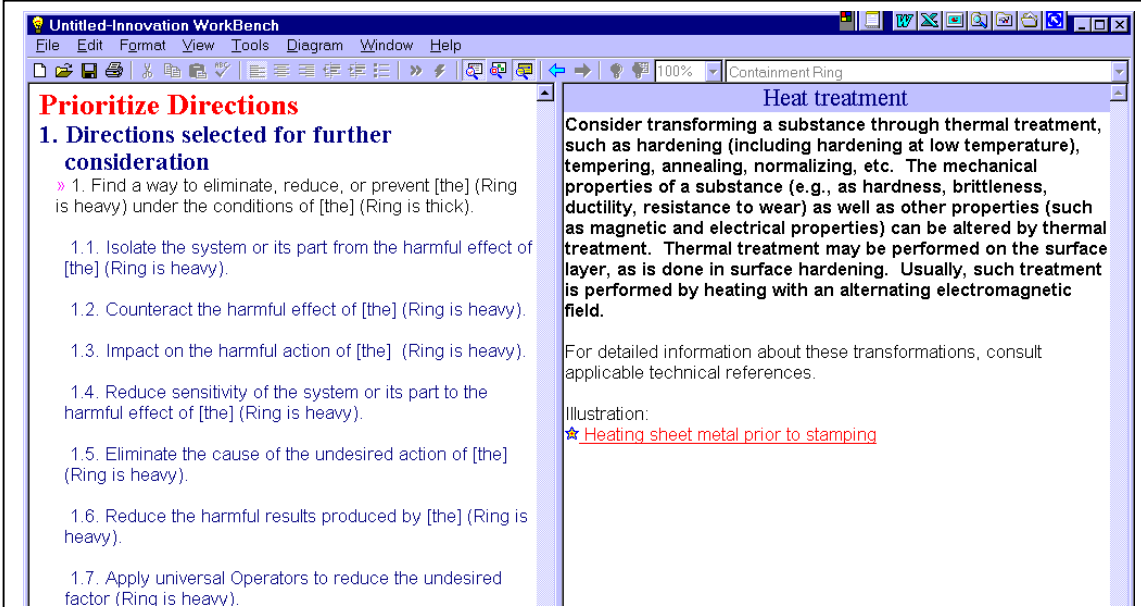
Auxiliary Operator: Generate mechanical stress



Idea # 7

Generate mechanical stress. For example, use additional rings which have been pressure-fitted to create a force directed toward the inside the ring.

Auxiliary Operator: Heat treatment



The screenshot shows the Innovation WorkBench interface. The left pane displays 'Prioritize Directions' with a list of 7 directions for further consideration. The right pane is titled 'Heat treatment' and contains a detailed paragraph about thermal treatment, followed by an illustration link: [★ Heating sheet metal prior to stamping](#).

Prioritize Directions
1. Directions selected for further consideration

- ▶ 1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).
 - 1.1. Isolate the system or its part from the harmful effect of [the] (Ring is heavy).
 - 1.2. Counteract the harmful effect of [the] (Ring is heavy).
 - 1.3. Impact on the harmful action of [the] (Ring is heavy).
 - 1.4. Reduce sensitivity of the system or its part to the harmful effect of [the] (Ring is heavy).
 - 1.5. Eliminate the cause of the undesired action of [the] (Ring is heavy).
 - 1.6. Reduce the harmful results produced by [the] (Ring is heavy).
 - 1.7. Apply universal Operators to reduce the undesired factor (Ring is heavy).

Heat treatment

Consider transforming a substance through thermal treatment, such as hardening (including hardening at low temperature), tempering, annealing, normalizing, etc. The mechanical properties of a substance (e.g., as hardness, brittleness, ductility, resistance to wear) as well as other properties (such as magnetic and electrical properties) can be altered by thermal treatment. Thermal treatment may be performed on the surface layer, as is done in surface hardening. Usually, such treatment is performed by heating with an alternating electromagnetic field.

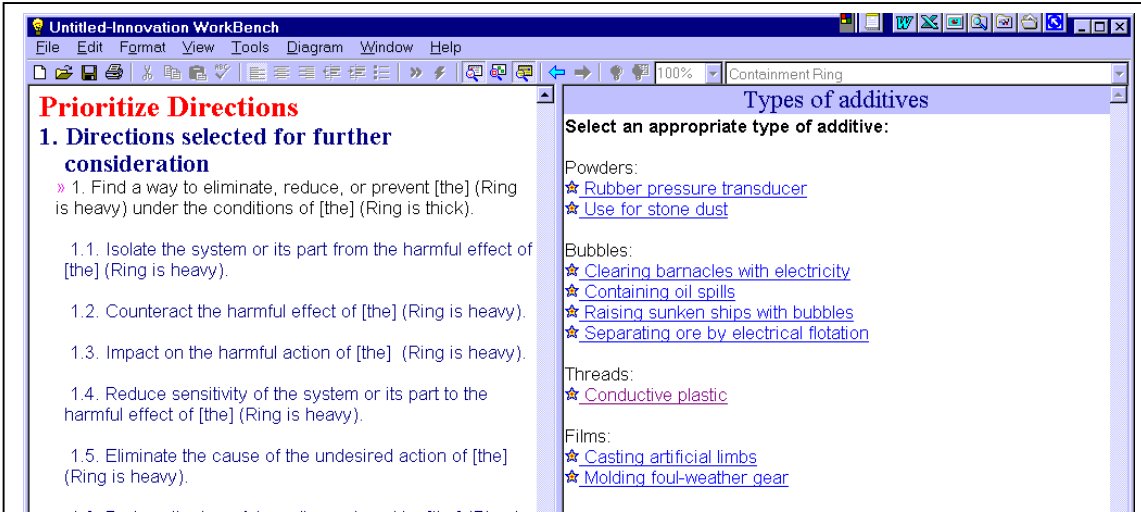
For detailed information about these transformations, consult applicable technical references.

Illustration:
★ [Heating sheet metal prior to stamping](#)

Idea # 8

Use thermal treatment to harden the ring material.

Auxiliary Operator: Introduce additives



The screenshot shows the Innovation WorkBench interface. The left pane displays 'Prioritize Directions' with a list of 5 directions for further consideration. The right pane is titled 'Types of additives' and lists categories: Powders, Bubbles, Threads, and Films, each with a star icon and a link.

Prioritize Directions
1. Directions selected for further consideration

- ▶ 1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).
 - 1.1. Isolate the system or its part from the harmful effect of [the] (Ring is heavy).
 - 1.2. Counteract the harmful effect of [the] (Ring is heavy).
 - 1.3. Impact on the harmful action of [the] (Ring is heavy).
 - 1.4. Reduce sensitivity of the system or its part to the harmful effect of [the] (Ring is heavy).
 - 1.5. Eliminate the cause of the undesired action of [the] (Ring is heavy).

Types of additives

Select an appropriate type of additive:

Powders:
★ [Rubber pressure transducer](#)
★ [Use for stone dust](#)

Bubbles:
★ [Clearing barnacles with electricity](#)
★ [Containing oil spills](#)
★ [Raising sunken ships with bubbles](#)
★ [Separating ore by electrical flotation](#)

Threads:
★ [Conductive plastic](#)

Films:
★ [Casting artificial limbs](#)
★ [Molding foul-weather gear](#)

Idea # 9

Use of special threads, such as in bullet protection vests.

Operator: Apply inflatable constructions

The screenshot shows the Innovation WorkBench interface. The main window is titled 'Containment Ring'. On the left, a pane titled 'Automobile air bags' contains two illustrations of a car interior. The top illustration shows a driver without an air bag, and the bottom illustration shows a driver with an air bag deployed. Text next to the illustrations explains the problem of inertia during an accident and how air bags solve it. The right pane is titled 'Apply inflatable constructions' and contains a list of suggestions for using inflatable constructions instead of mechanical ones. The suggestions include: Adjusting roof height, Automobile air bags, Cleaning a cylindrical reservoir, Hatchway roof design, Immobilizing a cow, Improved bed, Inflatable excavator, Inflating a satellite, Securing loads with inflatable material, Treating workpieces with sandpaper, Using inflated construction forms, Modular inflatable furniture, and Relieving high-altitude illness. Below the list, it notes that these constructions can be created by applying elastic tanks inflated with pressure.

Prioritize Directions
1. Directions selected for further consideration
» 1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).
1.1. Isolate the system or its part from the harmful effect of
Automobile air bags
An automobile driver involved in an accident experiences inertia upon impact, causing him to collide with the car. Although seat belts reduce this risk, they are often uncomfortable.
A safety feature which avoids these problems is the air bag. This system, which is activated by the impact of the automobile, inflates in an instant.

Apply inflatable constructions
Consider applying pneumatic (inflatable) constructions instead of mechanical ones.
Illustrations:
★ [Adjusting roof height](#)
★ [Automobile air bags](#)
★ [Cleaning a cylindrical reservoir](#)
★ [Hatchway roof design](#)
★ [Immobilizing a cow](#)
★ [Improved bed](#)
★ [Inflatable excavator](#)
★ [Inflating a satellite](#)
★ [Securing loads with inflatable material](#)
★ [Treating workpieces with sandpaper](#)
★ [Using inflated construction forms](#)
★ [Modular inflatable furniture](#)
★ [Relieving high-altitude illness](#)
In particular, create these constructions by applying elastic tanks that are inflated with excessive pressure or normal atmospheric pressure (provided that lower ambient pressure is present).
Illustrations:
★ [Filling empty space with balloons](#)
★ [Tilting with air bags](#)
★ [Vacuum clip](#)

Idea # 10

Replace the ring with the airbag inflated by the impeller burst.

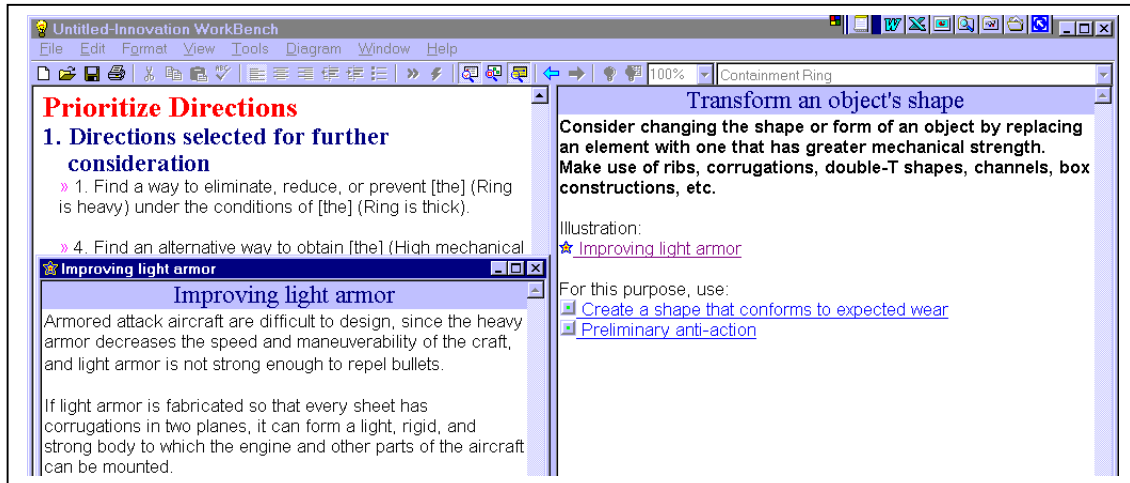
Direction 4.1: Improve the useful factor (Mechanical strength)

The screenshot shows the Innovation WorkBench interface. The main window is titled 'Containment Ring'. The left pane is titled 'Improve mechanical strength' and contains a list of directions for improving mechanical strength. The right pane is titled 'Improve mechanical strength' and contains a list of recommendations for improving the mechanical strength of a product. The recommendations include: Transform the shape of an object, Transform an object's micro-structure, Transform the aggregate state, Integration into a poly-system, Introduce a strengthening element, Anti-loading, and Introduce a strengthening additive. Below the list, it says 'See also: Eliminate a stressful operation'.

Prioritize Directions
1. Directions selected for further consideration
» 1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).
» 4. Find an alternative way to obtain [the] (High mechanical strength) that offers the following: provides or enhances [the] (Containing fragments), does not require [the] (Ring is thick).
4.1. Improve the useful factor (High mechanical strength).
4.2. Obtain the useful result without the use of [the] (High mechanical strength).
4.3. Increase effectiveness of the useful action of [the] (High mechanical strength).
4.4. Synthesize the new system to provide [the] (High mechanical strength).
4.5. Apply universal Operators to provide the useful factor (High mechanical strength).
4.6. Consider resources to provide the useful factor (High mechanical strength).

Improve mechanical strength
Consider the following recommendations (Operators) for improving the mechanical strength of a product:
★ [Transform the shape of an object](#)
★ [Transform an object's micro-structure](#)
★ [Transform the aggregate state](#)
★ [Integration into a poly-system](#)
★ [Introduce a strengthening element](#)
★ [Anti-loading](#)
★ [Introduce a strengthening additive](#)
See also:
★ [Eliminate a stressful operation](#)

Operator: Transform the shape of the object



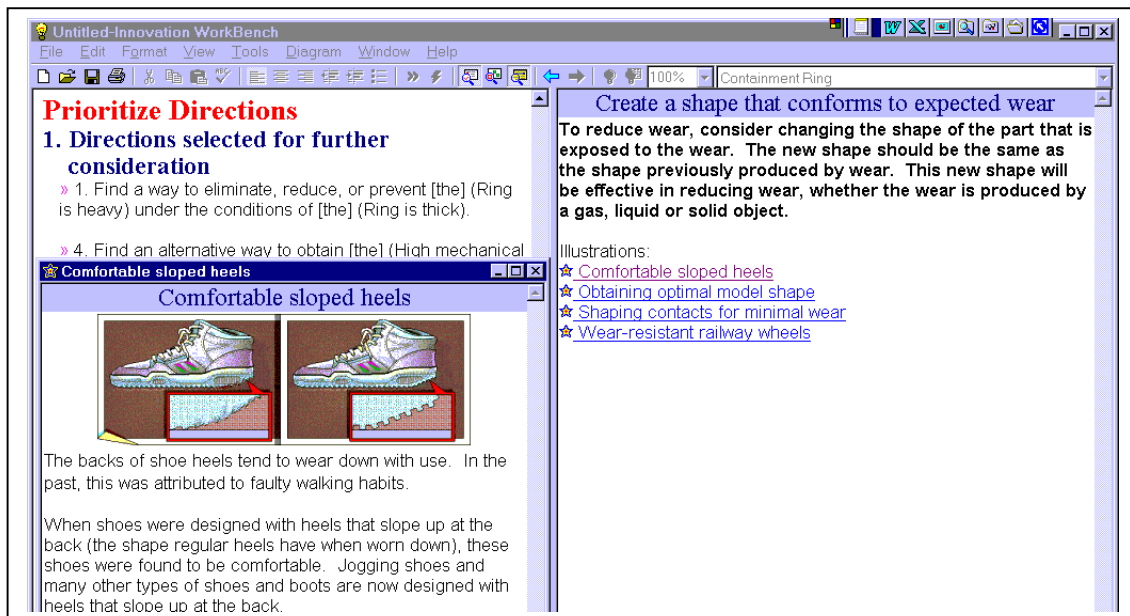
Idea # 11

Make a thin ring, which has reinforcing ribs. If the ribs are placed on the internal surface of the ring, flying fragments will lose a large amount of their energy smashing into the ribs.

Idea # 12

Make the ring corrugated in two planes.

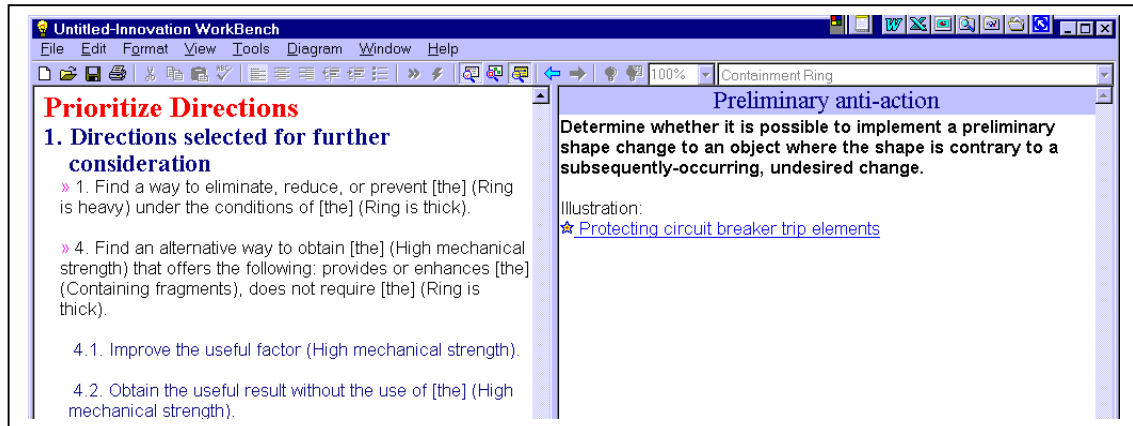
Auxiliary Operator: Create a shape conforming to expected wear



Idea # 13

Find where the rings usually break and reinforce these places.

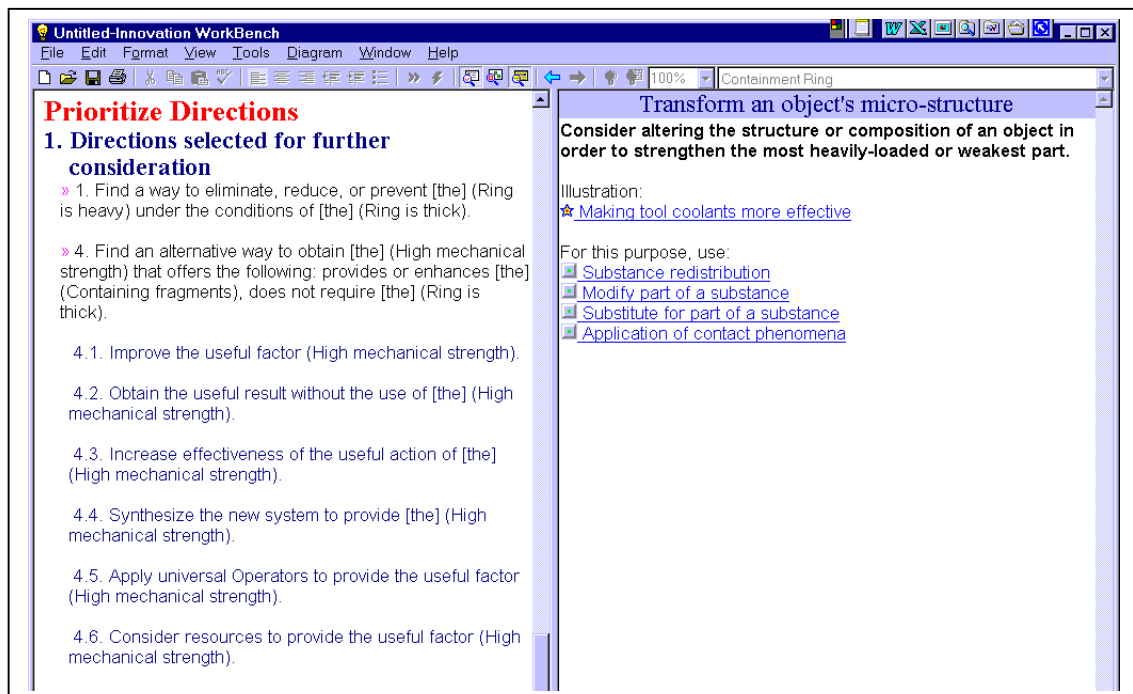
Auxiliary Operator: Preliminary anti-action



Idea # 14

Internal ribs with sharp edges can counteract flying fragments breaking them into smaller pieces.

Operator: Transform an object's micro-structure



Auxiliary Operator: Modify part of a substance

The screenshot shows the Innovation WorkBench interface. The main window is titled 'Untitled-Innovation WorkBench'. The left pane displays 'Prioritize Directions' with the following content:

Prioritize Directions
1. Directions selected for further consideration
» 1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).
» 4. Find an alternative way to obtain [the] (High mechanical strength) under the conditions of [the] (Ring is thick).

The right pane is titled 'Modify part of a substance' and contains the following text:

Modify part of a substance
A material or component can be made more heterogeneous by modifying part of it.

Illustrations:
★ [Centrifugal casting of metal rolls](#)
★ [Eliminating deformations in cooled steel components](#)
★ [Iron sheet texturing](#)
★ [Preventing steel from adhering to rollers](#)
★ [Thermite hardening for sandblasted designs](#)

For this purpose, use:
★ [Substance modification](#)

The bottom pane is titled 'Iron sheet texturing' and features an illustration of a rolling mill process. Below the illustration, the text reads:

To provide spatial texture to a rolled iron sheet, a heated metal plate is rolled to produce a relief surface. The projections are then cooled and the plate is rolled with smooth rollers to make the workpiece flat. Thus, a flat plate is produced which has a spatially-quenched texture in certain regions.

See idea # 8.

Auxiliary Operator: Substitute for a part of substance

The screenshot shows the Innovation WorkBench interface. The main window is titled 'Case study-Innovation WorkBench'. The left pane displays 'Prioritize Directions' with the following content:

Prioritize Directions
1. Directions selected for further consideration
» 1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).

The right pane is titled 'Substitute for part of a substance' and contains the following text:

Substitute for part of a substance
A material can be made more heterogeneous by:
• [replacing a part of the material by a "void"](#)
• [introducing an added layer of material](#)

Illustrations:
★ [Containers for jettisoning loads](#)
★ [Using glass panes in a fighter](#)

Also see relevant information in the [Innovation Guide](#)

The bottom pane is titled 'Containers for jettisoning loads' and features an illustration of an aircraft jettisoning a container. Below the illustration, the text reads:

When an object is jettisoned from an aircraft, the container and its contents are susceptible to damage from the subsequent impact. Even if the container is rigid enough to withstand the impact, damage to the load can result when it strikes the inner walls of the container.

The contents can be protected by manufacturing the container as a composite. The outer layer, made of a light, rigid material, is destroyed upon hitting the ground, and absorbs the energy of the impact. The inner layer is constructed of a flexible material which resists puncture and breakage.

This design reproduces an idea used with low-flying attack aircraft during World War II. Double armor was used in these aircraft: the outer layer was made of thin, breakable steel that absorbed or deflected the energy of a bullet or splinter; the inner layer was made of steel with a high plastic content which deformed, but was not punctured, upon impact.

Idea # 15

Use a multi-layer ring: additional strengthening rings, rings having different hardness and elasticity, rings which have a gap in-between them, filling the gap with energy-absorbing material.

The screenshot shows the 'Case study-Innovation WorkBench' interface. The main window displays 'Containment Ring' with a search result for 'Substitute for part of a substance'. The search results include:

- Substitute for part of a substance**
- A material can be made more heterogeneous by:
 - replacing a part of the material by a "void"
 - introducing an added layer of material
- Illustrations:
 - Containers for jettisoning loads
 - Using glass panes in a fighter
- Also see relevant information in the [Innovation Guide](#)

The 'Using glass panes in a fighter' illustration shows a fighter jet and a diagram of a window structure. The text below the illustration reads:

Bullet-proof glass windows used on fighter aircraft initially had a serious defect. When a bullet hit the window a network of cracks would form and obstruct vision.

Now the windows are formed of smaller panes of glass, cemented to an acrylic plastic sheet. Transparent adhesive is used to join the edges of the glass panes. When a bullet hits, only the affected pane is covered by cracks.

Idea # 16

Make the ring out of separate layers so cracks, which develop inside, won't spread.

Operator: Integration into a poly-system

The screenshot shows the 'Case study-Innovation WorkBench' interface. The main window displays 'Containment Ring' with a search result for 'Integrate into a poly-system'. The search results include:

- Integrate into a poly-system**
- To increase the resistance of an object to deformation, consider integrating it with other similar objects to form a single high-strength system.
- Illustrations:
 - Bonding glass plates for grinding
 - Transporting window glass
- For this purpose, use:
 - Homogeneous poly-system

The 'Transporting window glass' illustration shows a stack of glass sheets and a magnifying glass. The text below the illustration reads:

While being transported, sheets of window glass are separated by paper, protected by chips and packed into wooden cases. But even with these precautions, breakage often occurs.

In order to reduce breakage, window glass can be transported as a solid block rather than in separate sheets. Each glass sheet is covered with a thin film of oil, and the sheets are then joined together to form a block, which is much stronger than an individual sheet. Tests showed that when dropped from a height of two meters, the glass block sustained little damage; in contrast, more than 50% of the glass packed in the usual way was broken.

See idea # 15

Operator: Introduce a strengthening element

The screenshot shows the 'Case study-Innovation WorkBench' interface. The main window is titled 'Containment Ring'. On the left, under 'Prioritize Directions', there is a section '1. Directions selected for further consideration' with two numbered points. Below this is a window titled 'Metal-concrete' which contains two images: one showing a construction site with a rebar grid and another showing molten metal being poured into a form. The text describes metal-concrete as a building material that is strong, resistant to wear, and relatively inexpensive. On the right, under 'Introduce a strengthening element', there is a paragraph explaining that reinforcement can be temporary and easily removed. Below this are sections for 'Illustrations' (with links to 'Clamping complex parts', 'Drilling flaky materials', 'Metal-concrete', and 'Machining paper and foil'), 'Also try:' (with a link to 'Eliminate a stressful action'), and 'Also see:' (with a link to 'Add an object with required properties').

Idea # 17

Use metal concrete or other composite materials

Operator: Anti-loading

The screenshot shows the 'Case study-Innovation WorkBench' interface. The main window is titled 'Containment Ring'. On the left, under 'Prioritize Directions', there is a section '1. Directions selected for further consideration' with two numbered points. The second point is expanded into four sub-points (4.1 to 4.4). On the right, under 'Anti-loading', there is a paragraph explaining that pre-loading can counter undesirable stress. Below this is a section for 'This effect is applied in creating:' with a link to 'Pre-stressed constructions'. At the bottom, there is an 'Illustration:' section with a link to 'Using a roller to reduce vibration'.

Auxiliary Operator: Use pre-stressed constructions

The screenshot shows the 'Case study-Innovation WorkBench' interface. The main window displays 'Strengthening gun barrels' with a diagram of a gun barrel being reinforced with preheated steel rings. The diagram shows a cross-section of the barrel with red arrows indicating the inward force of the rings as they cool. The text explains that these rings prevent the barrel from rupturing when fired.

On the right side, there is a panel titled 'Using pre-stressed constructions'. It states: 'Inner stress, distributed in the most desirable way in an object or system, can be created in advance (during manufacturing, construction, etc.)'. Below this, it lists 'Illustrations:' with links to 'Designing improved flywheels', 'Dismantling compression joints', 'Strengthening gun barrels', and 'Tightening joints with rust'. It also explains that to create inner stress, different parts must be oppositely stressed and lists 'Integrating objects' and 'Partitioning objects' as methods. Finally, it mentions 'Also see: Building bi-systems'.

Idea # 18

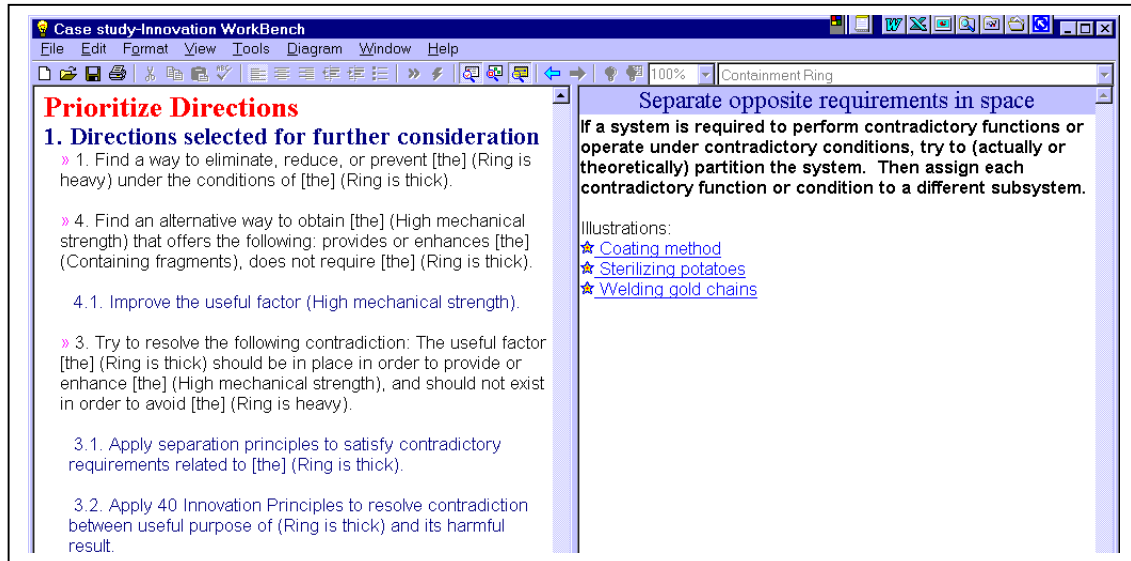
Create inner stresses inside the ring: This can be done, for example, using wiring, banding, double ring structure, etc.

Direction 3.1: Apply separation principles to satisfy contradictory requirements related to [the] (Ring is thick)

The screenshot shows the 'Case study-Innovation WorkBench' interface. The main window displays 'Separation' principles. The text states: 'The following Operators can address any situation with contradictory requirements:'. Below this, it lists several operators: 'Separate opposite requirements in space', 'Separate opposite requirements in time', 'Optimize characteristics in time', 'Separate opposite requirements between the whole object and its parts', 'Separate opposite requirements via changing conditions', 'Separate an impeding part from an object', and 'Separate (remove) a required part from an object'.

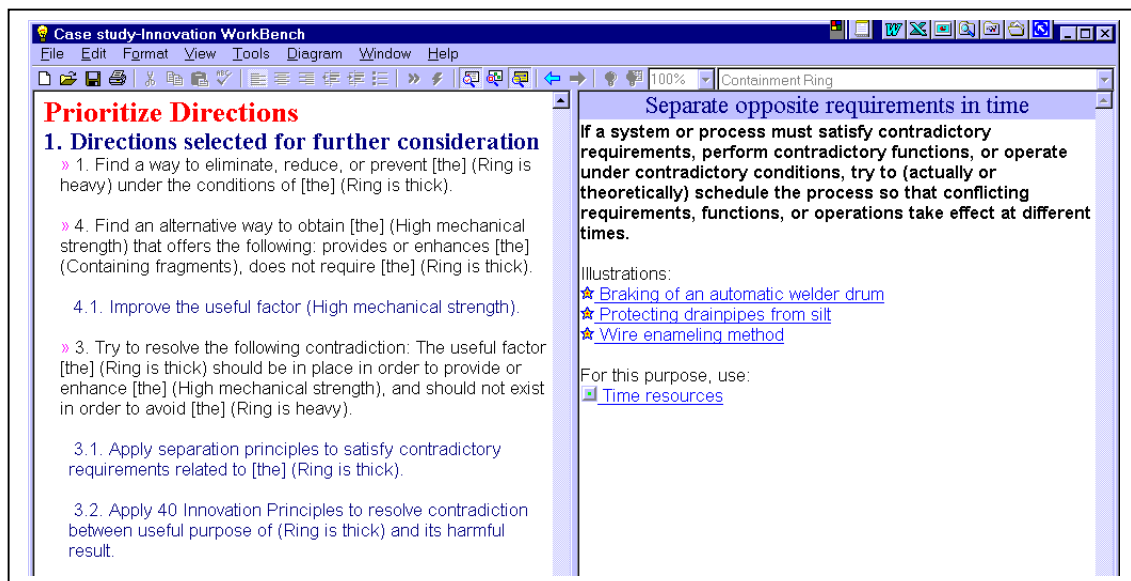
On the left side, there is a panel titled 'Prioritize Directions'. It contains '1. Directions selected for further consideration' with several sub-points. Point 1 is 'Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick)'. Point 4 is 'Find an alternative way to obtain [the] (High mechanical strength) that offers the following: provides or enhances [the] (Containing fragments), does not require [the] (Ring is thick)'. Under point 4, there are sub-points: '4.1. Improve the useful factor (High mechanical strength)', '3. Try to resolve the following contradiction: The useful factor [the] (Ring is thick) should be in place in order to provide or enhance [the] (High mechanical strength), and should not exist in order to avoid [the] (Ring is heavy)', '3.1. Apply separation principles to satisfy contradictory requirements related to [the] (Ring is thick)', and '3.2. Apply 40 Innovation Principles to resolve contradiction between useful purpose of (Ring is thick) and its harmful result'.

Operator: Separate opposite requirements in space



See ideas ## 5, 11,13,15: Ring with variable thickness, ribs; multi-layer ring.

Operator: Separate requirements in time



See idea # 10: Replace the ring with the airbag inflated by the impeller burst.

Operator: Separate opposite requirements between parts and the whole object

The screenshot shows the 'Case study-Innovation WorkBench' interface. The left pane is titled 'Prioritize Directions' and contains a list of directions for further consideration. The right pane is titled 'Separate opposite requirements between the whole object and its parts' and contains a definition of the operator, illustrations, and a list of examples.

Prioritize Directions

1. Directions selected for further consideration

- » 1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).
- » 4. Find an alternative way to obtain [the] (High mechanical strength) that offers the following: provides or enhances [the] (Containing fragments), does not require [the] (Ring is thick).
 - 4.1. Improve the useful factor (High mechanical strength).
- » 3. Try to resolve the following contradiction: The useful factor [the] (Ring is thick) should be in place in order to provide or enhance [the] (High mechanical strength), and should not exist in order to avoid [the] (Ring is heavy).
 - 3.1. Apply separation principles to satisfy contradictory requirements related to [the] (Ring is thick).
 - 3.2. Apply 40 Innovation Principles to resolve contradiction between useful purpose of (Ring is thick) and its harmful result.

Separate opposite requirements between the whole object and its parts

If a system is required to perform contradictory functions or operate under contradictory conditions, try to partition the system and assign one of the contradictory functions or conditions to a subsystem (or several subsystems). Let the system as a whole retain the remaining functions and conditions.

Illustrations:

- ★ [Gripping workpieces of complex shape](#)
- ★ [Antenna made of beads](#)

See idea # 1: Make the ring as an assembly from light parts that are easy to move for testing.

Operator: Separate requirements via changing conditions

The screenshot shows the 'Case study-Innovation WorkBench' interface. The left pane is titled 'Prioritize Directions' and contains a list of directions for further consideration. The right pane is titled 'Separate opposite requirements via changing conditions' and contains a definition of the operator, illustrations, and a list of examples.

Prioritize Directions

1. Directions selected for further consideration

- » 1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).
- » 4. Find an alternative way to obtain [the] (High mechanical strength) that offers the following: provides or enhances [the] (Containing fragments), does not require [the] (Ring is thick).
 - 4.1. Improve the useful factor (High mechanical strength).
- » 3. Try to resolve the following contradiction: The useful factor [the] (Ring is thick) should be in place in order to provide or enhance [the] (High mechanical strength), and should not exist in order to avoid [the] (Ring is heavy).
 - 3.1. Apply separation principles to satisfy contradictory requirements related to [the] (Ring is thick).
 - 3.2. Apply 40 Innovation Principles to resolve contradiction between useful purpose of (Ring is thick) and its harmful result.

Separate opposite requirements via changing conditions

If a system or process must satisfy contradictory requirements, perform contradictory functions, or operate under contradictory conditions, try to identify a parameter or condition that can change so the system can meet one requirement under one condition and the opposite requirement under another condition.

Illustrations:

- ★ [Adjusting ski-to-snow contact](#)
- ★ [Alcohol-free wine](#)
- ★ [Cleansing parts before repair](#)
- ★ [Double-torch furnace](#)
- ★ [Batch drying](#)
- ★ [Silkworm cocoon treatment](#)
- ★ [Using a two-sided photographic plate](#)
- ★ [Using ball hydraulics](#)
- ★ [Using the difference between electrical and sound propagation](#)

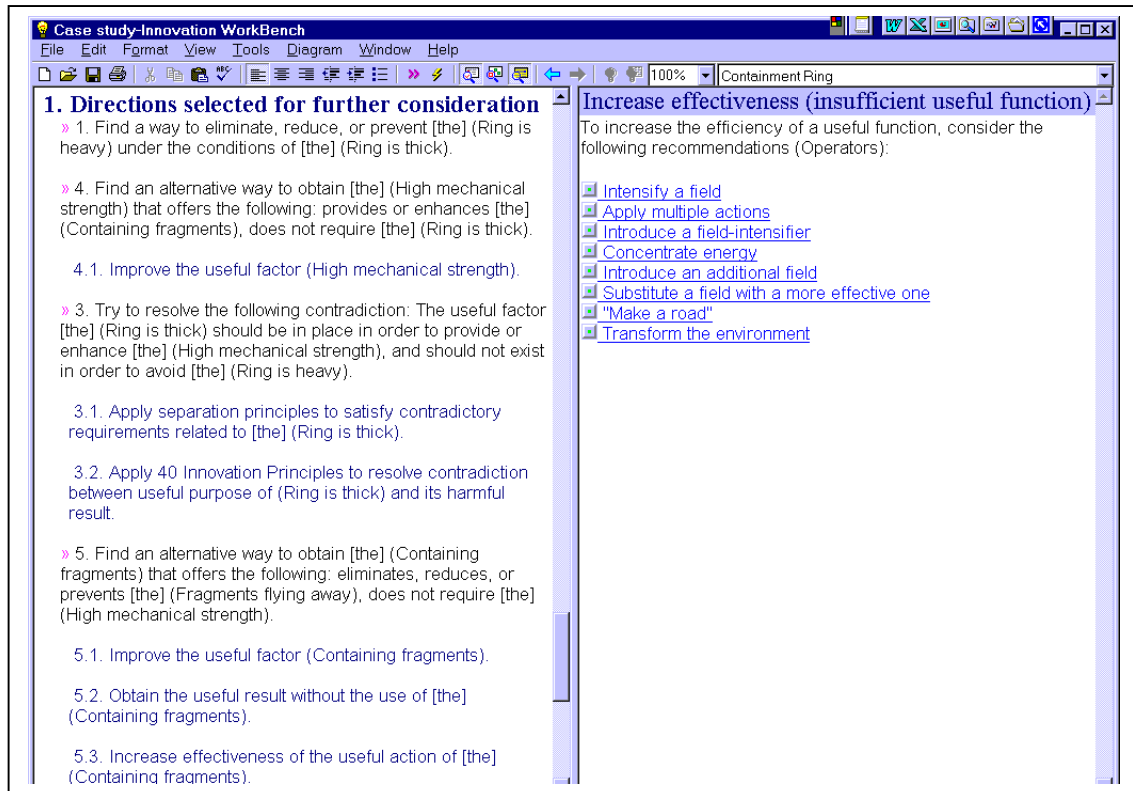
See also:

- ★ [Differential influence \(separation\)](#)

Idea # 19

Change the ring thickness or strength or other containing capabilities at the moment of impeller burst.

Direction 5.3: Increase effectiveness of the useful action of [the] (containing fragments)



1. Directions selected for further consideration

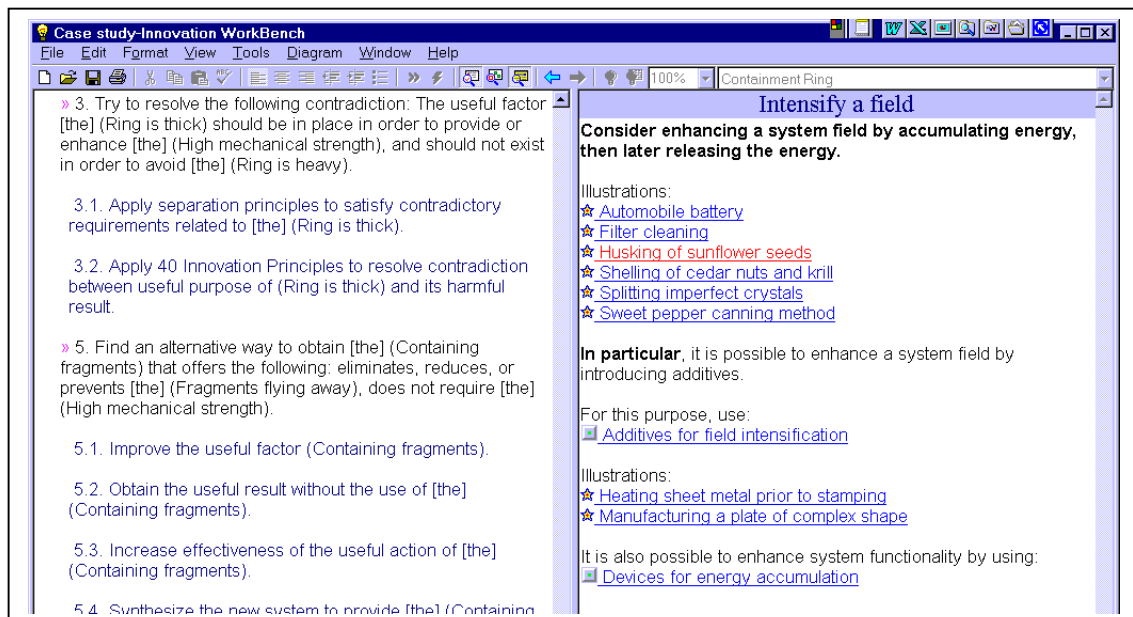
- » 1. Find a way to eliminate, reduce, or prevent [the] (Ring is heavy) under the conditions of [the] (Ring is thick).
- » 4. Find an alternative way to obtain [the] (High mechanical strength) that offers the following: provides or enhances [the] (Containing fragments), does not require [the] (Ring is thick).
 - 4.1. Improve the useful factor (High mechanical strength).
- » 3. Try to resolve the following contradiction: The useful factor [the] (Ring is thick) should be in place in order to provide or enhance [the] (High mechanical strength), and should not exist in order to avoid [the] (Ring is heavy).
 - 3.1. Apply separation principles to satisfy contradictory requirements related to [the] (Ring is thick).
 - 3.2. Apply 40 Innovation Principles to resolve contradiction between useful purpose of (Ring is thick) and its harmful result.
- » 5. Find an alternative way to obtain [the] (Containing fragments) that offers the following: eliminates, reduces, or prevents [the] (Fragments flying away), does not require [the] (High mechanical strength).
 - 5.1. Improve the useful factor (Containing fragments).
 - 5.2. Obtain the useful result without the use of [the] (Containing fragments).
 - 5.3. Increase effectiveness of the useful action of [the] (Containing fragments).

Increase effectiveness (insufficient useful function)

To increase the efficiency of a useful function, consider the following recommendations (Operators):

- Intensify a field
- Apply multiple actions
- Introduce a field-intensifier
- Concentrate energy
- Introduce an additional field
- Substitute a field with a more effective one
- "Make a road"
- Transform the environment

Operator: Intensify a field



Intensify a field

Consider enhancing a system field by accumulating energy, then later releasing the energy.

Illustrations:

- ★ [Automobile battery](#)
- ★ [Filter cleaning](#)
- ★ [Husking of sunflower seeds](#)
- ★ [Shelling of cedar nuts and krill](#)
- ★ [Splitting imperfect crystals](#)
- ★ [Sweet pepper canning method](#)

In particular, it is possible to enhance a system field by introducing additives.

For this purpose, use:

- Intensify a field
- Introduce an additional field

Illustrations:

- ★ [Heating sheet metal prior to stamping](#)
- ★ [Manufacturing a plate of complex shape](#)

It is also possible to enhance system functionality by using:

- Intensify a field
- Introduce an additional field

Auxiliary Operator: Substances as energy accumulators

The screenshot shows the 'Case study-Innovation WorkBench' interface. The main window displays the Auxiliary Operator 'Substances as energy accumulators' with the following text:

Try to make use of special substances that are capable of accumulating and then releasing energy, such as explosives, thermites, elastic substances, etc.

3. Try to resolve the following contradiction: The useful factor [the] (Ring is thick) should be in place in order to provide or enhance [the] (High mechanical strength), and should not exist in order to avoid [the] (Ring is heavy).

3.1. Apply separation principles to satisfy contradictory requirements related to [the] (Ring is thick).

3.2. Apply 40 Innovation Principles to resolve contradiction between useful purpose of (Ring is thick) and its harmful result.

5. Find an alternative way to obtain [the] (Containing fragments) that offers the following: eliminates, reduces, or prevents [the] (Fragments flying away), does not require [the] (High mechanical strength).

Idea # 20

Explode the ring in the moment of the impeller burst. Use the explosion wave to create a counteracting force.

Operator: Concentrate energy

The screenshot shows the 'Case study-Innovation WorkBench' interface. The main window displays the Operator 'Concentrate energy' with the following text:

Consider concentrating the action at a specific location.

Illustrations:

- ★ [Crushing gallstones](#)
- ★ [Heating frozen earth with solar radiation](#)
- ★ [Improving bomb design](#)
- ★ [Increasing lighting efficiency](#)
- ★ [Plasma heating without electrode contamination](#)

In particular, consider changing from three-dimensional action to surface action, or to action at a point.

Illustrations:

- ★ [Controlling the release of medication](#)
- ★ [Rotating die forging](#)
- ★ [Using bubbles in wastepaper recycling](#)

For concentration, use different geometrical shapes (forms).

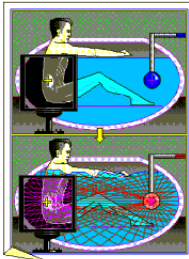
Illustration:

- ★ [Ventilating quarries](#)

Also see:

- ★ [Create unidirectional action](#)

Crushing gallstones



In the past, the treatment of gallstones required surgery, which was risky and traumatic.

A newer treatment eliminates the need for surgery. The patient sits in an ellipsoid-shaped water bath. With the help of an X-ray screen, an apparatus is placed such that the gallstone is at the focus of the ellipsoid. An electrohydraulic shock wave is generated at the ellipsoid's other focus. The shock wave passes

through the water and body tissue (the density of which is close to that of water). Due to the geometric laws governing ellipsoids, the energy from the shock wave is directed at the second focus, crushing the gallstone.

Idea # 21

Disintegrate the fragments.

Idea # 22

Utilize special geometrical shapes to create traps for the fragments. For example, make the ring in the form of spring.

Operator: Introduce an additional field

Case study-Innovation WorkBench

File Edit Format View Tools Diagram Window Help

100% Containment Ring

3. Try to resolve the following contradiction: The useful factor [the] (Ring is thick) should be in place in order to provide or enhance [the] (High mechanical strength), and should not exist in order to avoid [the] (Ring is heavy).

3.1. Apply separation principles to satisfy contradictory requirements related to [the] (Ring is thick).

Breaking rock with water and steam

Breaking rock with water and steam

The effectiveness of water cannons used to break rock is usually limited by the maximum water pressure that can be generated.

To avoid this problem, water for the cannon can be superheated to 200-300 degrees C. This water will not turn to steam as long as it remains under pressure. When the superheated water is sprayed from the cannon, it impacts the rock face and also enters small cracks in the rock. After entering the cracks, the water changes to steam; the expansion of the steam acts to break the rock apart.

Introduce an additional field

A system function can be enhanced by adding another field or by adding a substance that "contains" a field.

Illustrations:

- ★ [Breaking rock with water and steam](#)
- ★ [Collecting more pollen](#)
- ★ [Increasing honing accuracy](#)
- ★ [Heating when sawing](#)
- ★ [Destroying dams](#)
- ★ [Breaking up rock masses](#)
- ★ [Obtaining accurate biological sections](#)
- ★ [Polishing with molten metal and magnetism](#)
- ★ [Increasing saw effectiveness](#)
- ★ [Jet-powered brush](#)
- ★ [Manufacturing metal shot](#)
- ★ [Measuring temperature with a bimetallic plate](#)
- ★ [Odor-releasing watch](#)
- ★ [Removal of insulation layers](#)
- ★ [Rolling thin sheets](#)
- ★ [Super-precise grinding](#)
- ★ [Using magnetism to improve well grouting](#)
- ★ [Using steam to blow pipes](#)
- ★ [Using turbulence to stabilize a bomb](#)

To help in selecting the second field, use:

- ☑ [Choose a field](#)

In particular, consider superimposed waves or pulses as a second field.

For this purpose, use:

- ☑ [Transit to a varying field](#)
- ☑ [Transit to a pulsed field](#)

Idea # 23

Create a combination of pressurized air and liquid to counteract fragments.

Operator: Substitute a field with a more effective one

» 3. Try to resolve the following contradiction: The useful factor [the] (Ring is thick) should be in place in order to provide or enhance [the] (High mechanical strength), and should not exist in order to avoid [the] (Ring is heavy).

3.1. Apply separation principles to satisfy contradictory requirements related to [the] (Ring is thick).

Cutting steel pipes with a directed explosion

The methods conventionally used to cut steel pipes are labor-intensive, time-consuming, and inconvenient in extreme environments. (Some of these methods employ the use of gas or a single-point cutting tool.)

A directed explosion can be used as an alternative cutting method. A metal pipe filled with an explosive material curved into a ring can be installed where the pipe is to be cut. This procedure ensures a simultaneous cut around the diameter of the pipe, and allows the cutting of any angle specified with respect to the pipe's longitudinal axis.

Substitute a field with a more effective one

A system function can be enhanced by replacing the field that produces the existing function with a more effective field.

Illustrations:

- ★ [Concentrating bio-suspensions](#)
- ★ [Cutting steel pipes with a directed explosion](#)
- ★ [Disinfecting transport facilities](#)
- ★ [Fabricating a microwire capacitor](#)
- ★ [Phased arrays](#)
- ★ [Setting tires on wheels](#)
- ★ [Silkworm cocoon treatment](#)
- ★ [Using ultrasound to delay electronic signals](#)

For this purpose, use:

- [Field transformation](#)

See idea # 20: Counteracting explosion.

Operator: "Make a road"

» 3. Try to resolve the following contradiction: The useful factor [the] (Ring is thick) should be in place in order to provide or enhance [the] (High mechanical strength), and should not exist in order to avoid [the] (Ring is heavy).

3.1. Apply separation principles to satisfy contradictory requirements related to [the] (Ring is thick).

Avoiding arrow accidents

In the movies, when an arrow strikes an actor, a shield (such as a wooden board) under the actor's clothing protects him from harm. But what would happen if the archer mistakenly hits an unprotected part of the actor's body?

To ensure that the arrow accurately reaches its target, a nearly-invisible fishing line can be threaded through the arrow, then stretched and attached to the target spot.

"Make a road"

Try to make the preferred way easy for the tool(s).

Illustrations:

- ★ [Avoiding arrow accidents](#)
- ★ [Efficient lightning rod](#)
- ★ [Isolating a microbe](#)
- ★ [Rescuing a man from a chimney](#)
- ★ [Sinking boreholes by explosion](#)
- ★ [Starting the arc for automated welding](#)

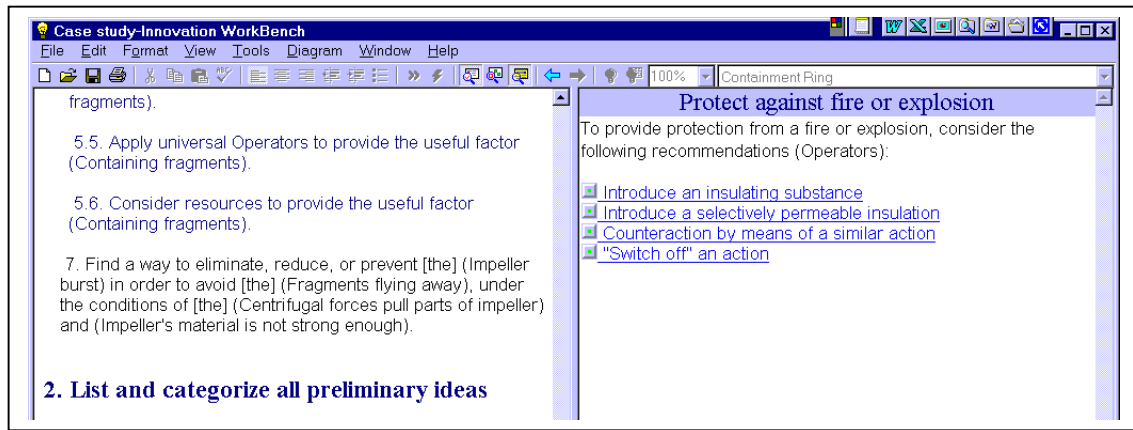
Idea # 24

Create a safe pathway for fragments.

Idea # 25

Introduce strong fibers in the impeller blades that are capable to hold fragments after blades crash.

Direction 7a: Protect against fire or explosion



fragments).

5.5. Apply universal Operators to provide the useful factor (Containing fragments).

5.6. Consider resources to provide the useful factor (Containing fragments).

7. Find a way to eliminate, reduce, or prevent [the] (Impeller burst) in order to avoid [the] (Fragments flying away), under the conditions of [the] (Centrifugal forces pull parts of impeller) and (Impeller's material is not strong enough).

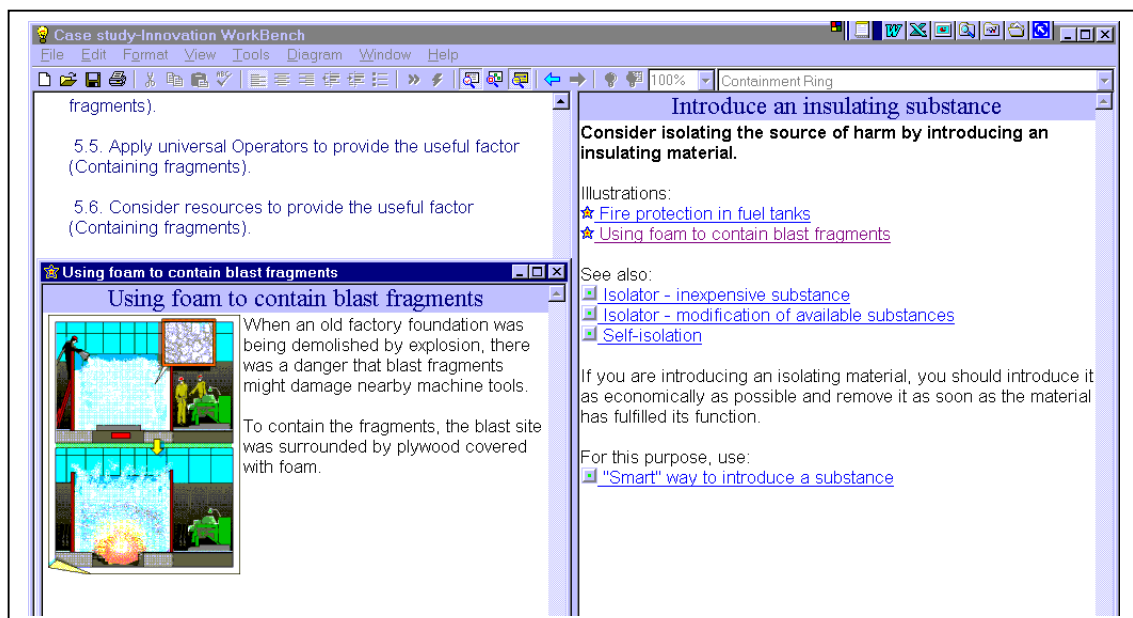
2. List and categorize all preliminary ideas

Protect against fire or explosion

To provide protection from a fire or explosion, consider the following recommendations (Operators):

- [Introduce an insulating substance](#)
- [Introduce a selectively permeable insulation](#)
- [Counteraction by means of a similar action](#)
- ["Switch off" an action](#)

Operator: Introduce an insulating substance



fragments).

5.5. Apply universal Operators to provide the useful factor (Containing fragments).

5.6. Consider resources to provide the useful factor (Containing fragments).

Using foam to contain blast fragments

When an old factory foundation was being demolished by explosion, there was a danger that blast fragments might damage nearby machine tools.

To contain the fragments, the blast site was surrounded by plywood covered with foam.

Introduce an insulating substance

Consider isolating the source of harm by introducing an insulating material.

Illustrations:

- ★ [Fire protection in fuel tanks](#)
- ★ [Using foam to contain blast fragments](#)

See also:

- [Isolator - inexpensive substance](#)
- [Isolator - modification of available substances](#)
- [Self-isolation](#)

If you are introducing an isolating material, you should introduce it as economically as possible and remove it as soon as the material has fulfilled its function.

For this purpose, use:

- ["Smart" way to introduce a substance](#)

Idea # 26

Use foam or foam-like material to absorb energy. Apparently, we need special type of foam like metal foam. We can also consider other fillings that can absorb energy (see also idea # 3).

Operator: Counteraction by means of a similar action

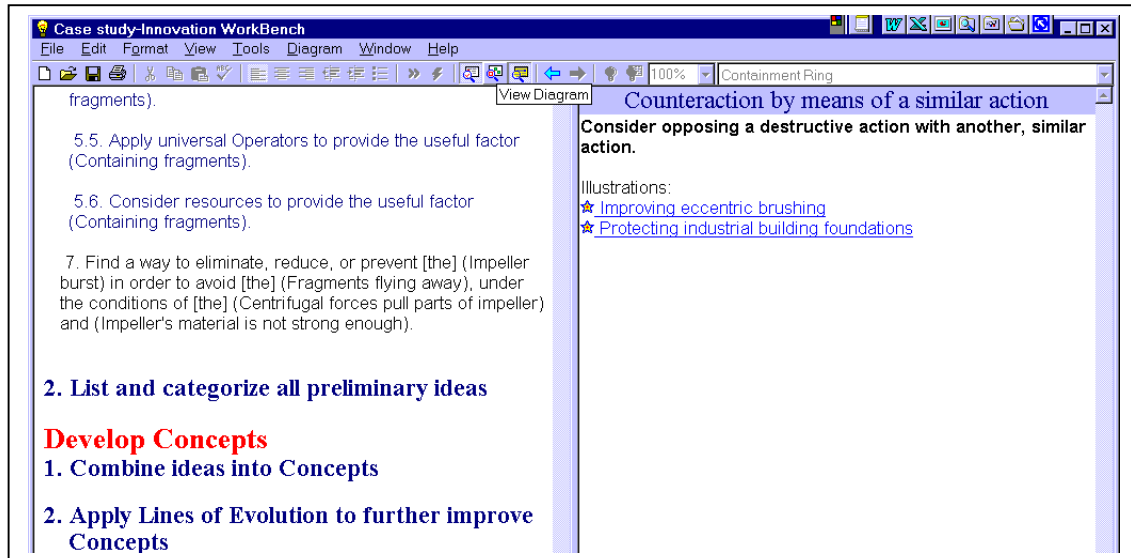
The screenshot shows the 'Case study-Innovation WorkBench' interface. The main window displays the 'Counteraction by means of a similar action' operator. The left pane contains text: 'fragments).', '5.5. Apply universal Operators to provide the useful factor (Containing fragments).', '5.6. Consider resources to provide the useful factor (Containing fragments).', and a section titled 'Fighting fire with fire' which includes an illustration of a person fighting a fire and text explaining that brush fires can be destructive and can be controlled by starting a backfire. The right pane shows the operator's definition: 'Counteraction by means of a similar action' and 'Consider opposing an action that causes a harmful effect with another, similar action.' Below this is an illustration of 'Fighting fire with fire'.

See idea # 20: Counteracting explosion.

Direction 7b: Reduce destruction

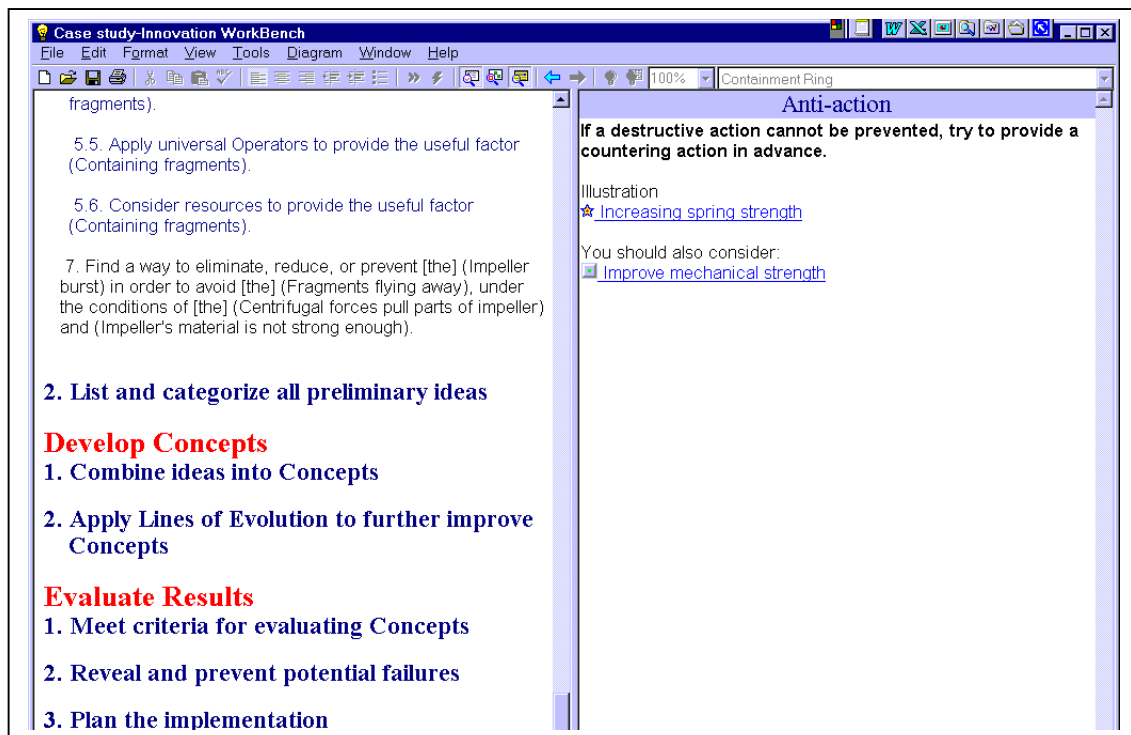
The screenshot shows the 'Case study-Innovation WorkBench' interface. The main window displays the 'Reduce deformation, displacement, shock, vibration or destruction' operator. The left pane contains text: 'fragments).', '5.5. Apply universal Operators to provide the useful factor (Containing fragments).', '5.6. Consider resources to provide the useful factor (Containing fragments).', and '7. Find a way to eliminate, reduce, or prevent [the] (Impeller burst) in order to avoid [the] (Fragments flying away), under the conditions of [the] (Centrifugal forces pull parts of impeller) and (Impeller's material is not strong enough)'. Below this is a section titled '2. List and categorize all preliminary ideas' which includes 'Develop Concepts' (1. Combine ideas into Concepts, 2. Apply Lines of Evolution to further improve Concepts) and 'Evaluate Results' (1. Meet criteria for evaluating Concepts). The right pane shows the operator's definition: 'Reduce deformation, displacement, shock, vibration or destruction' and 'To eliminate or reduce deformation, displacement, shock, vibration or destruction, consider the following recommendations (Operators):'. Below this is a list of operators: 'Combine with another undesired action', 'Counteraction by means of a similar action', 'Anti-action', 'Draw off an undesired action', 'Local slackening of an action', 'Slacken an action', 'Mask defects', 'Introduce an isolating substance', and 'Parallel restoration'.

Operator: Counteraction by means of a similar action



See ideas ## 20, 21: counteracting explosion, disintegrating fragments

Operator: Anti-action



Consideration # 1

We can apply all ideas obtained for improving mechanical strength of the ring to the impeller blades.

Operator: Draw off an undesired action

The screenshot shows the 'Case study-Innovation WorkBench' interface. The left pane contains a list of ideas and instructions for developing concepts. The right pane displays the 'Draw off an undesired action' operator, which includes a definition, illustrations, and a recommendation to consider 'Smart' ways to introduce a substance.

fragments).

5.5. Apply universal Operators to provide the useful factor (Containing fragments).

5.6. Consider resources to provide the useful factor (Containing fragments).

7. Find a way to eliminate, reduce, or prevent [the] (Impeller burst) in order to avoid [the] (Fragments flying away), under the conditions of [the] (Centrifugal forces pull parts of impeller) and (Impeller's material is not strong enough).

2. List and categorize all preliminary ideas

Develop Concepts

1. Combine ideas into Concepts

2. Apply Lines of Evolution to further improve Concepts

"Draw off" an undesired action

To protect a system or process from destruction, consider introducing a mediating component or subsystem that will transform or absorb (partially or completely) the harmful effect.

Illustrations:

- ★ [Increasing the seismic stability of a dam](#)
- ★ [Preventing pipe damage from freezing](#)
- ★ [Protecting buried cables](#)
- ★ [Using gas to prevent damage from freezing](#)

If you introduce a mediating component or subsystem, it should be done as economically as possible. Furthermore, the mediator should be removed as soon as it has fulfilled its function.

For this purpose, consider:

- ★ ["Smart" ways to introduce a substance](#)

See idea # 26: absorb the energy of fragments

Operator: Local slackening of an action

The screenshot shows the 'Case study-Innovation WorkBench' interface. The left pane contains a list of ideas and instructions for developing concepts. The right pane displays the 'Local slackening of an action' operator, which includes a definition, an illustration, and a recommendation to consider changing the contact point to a line, surface, or volume contact.

fragments).

5.5. Apply universal Operators to provide the useful factor (Containing fragments).

5.6. Consider resources to provide the useful factor (Containing fragments).

7. Find a way to eliminate, reduce, or prevent [the] (Impeller burst) in order to avoid [the] (Fragments flying away), under the conditions of [the] (Centrifugal forces pull parts of impeller) and (Impeller's material is not strong enough).

2. List and categorize all preliminary ideas

Develop Concepts

1. Combine ideas into Concepts

2. Apply Lines of Evolution to further improve Concepts

Local slackening of an action

If it is impossible to eliminate a harmful effect (such as a destructive action or overheating, for example) consider reducing the effect at a specific place and/or for a specific period of time.

Also consider reducing the harmful effect by distributing or diluting it (for instance, by diverting some of the energy that causes the effect).

Illustration:

- ★ [Equalizing sheave loading](#)

If the harmful effect takes place at a point, consider changing the contact point to a line, surface, or volume contact. Consider as well the possibility of rolling contact.

Illustration:

- ★ [Plasma generator](#)

Also try:

- ★ [Rushing through](#)

Idea # 27

Define less dangerous directions and redirect fragments to these directions.

Idea # 28

Distributing the harmful energy between more fragments (see also ideas # 7 and 21: reducing energy /mass of fragments)

Operator: Slacken an action (Weaken an undesired action by prolonging it)

The screenshot displays the 'Case study-Innovation WorkBench' application. The main window shows a list of ideas, with 'Using foam to granulate nickel' selected. This idea is detailed in a sub-window, which includes an illustration of nickel granulation. The illustration shows red spheres (molten nickel) falling through a layer of blue foam into water. Text explains that radiation heating slows the cooling process, and foam slows the falling drops, giving them time to cool before entering the water. A right-hand panel titled 'Weaken an undesired action by prolonging it' provides a definition: 'Consider weakening the action that causes a harmful effect by stretching out the time in which the action takes place.' It lists several related ideas, including 'Bathyscaph guide rope', 'Increasing the service life of a gas turbine engine', 'Moderating parachute opening force', and 'Using foam to granulate nickel'. An 'Also see:' section points to 'Divide into a set of operations'.

Idea # 29

Create a special pathway (spiral) to trap the fragments and to reduce their energy while traveling through the spiral route (see ideas ## 22 and 24). Also, see idea # 26: absorb the energy.

Direction15.1: Improve the useful factor (Test convenience)¹

The screenshot shows the 'Case study-Innovation WorkBench' interface. The left pane displays a list of operators for 'Improve convenience', including: 5.3. Increase effectiveness of the useful action of [the] (Containing fragments). 7. Find a way to eliminate, reduce, or prevent [the] (Impeller burst) in order to avoid [the] (Fragments flying away), under the conditions of [the] (Centrifugal forces pull parts of impeller) and (Impeller's material is not strong enough). 15. Find an alternative way to obtain [the] (Test convenience) that is not influenced by [the] (Ring is heavy). 15.1. Improve the useful factor (Test convenience). 15.2. Obtain the useful result without the use of [the] (Test convenience). 15.3. Increase effectiveness of the useful action of [the] (Test convenience). 15.4. Synthesize the new system to provide [the] (Test convenience). 15.5. Protect [the] (Test convenience) from the harmful influence of [the] (Ring is heavy). 15.6. Apply universal Operators to provide the useful factor (Test convenience).

The right pane is titled 'Improve convenience' and contains the following text: 'To make your system more convenient, consider the following recommendations (Operators):' followed by a list of operators: Make an object dismountable, Self-service, Apply a model or copy, Apply disposable objects, Vary optical characteristics, Vary transparency, Apply a mediator, Apply inflatable constructions, Optimize characteristics, Adapt a tool to a person. Below this, it says 'To improve the ability of your system to be transported, consider the following:' followed by a list of operators: Divide into "heavy" and "light" parts, Move a heavy object, Optimize characteristics, Apply inflatable constructions, Anti-weight 1, Anti-weight 2, Compensate by means of other forces, "Retain the available" principle. At the bottom, it says 'Also see:' followed by 'Transient use of a substance'.

Operator: Make an object dismountable

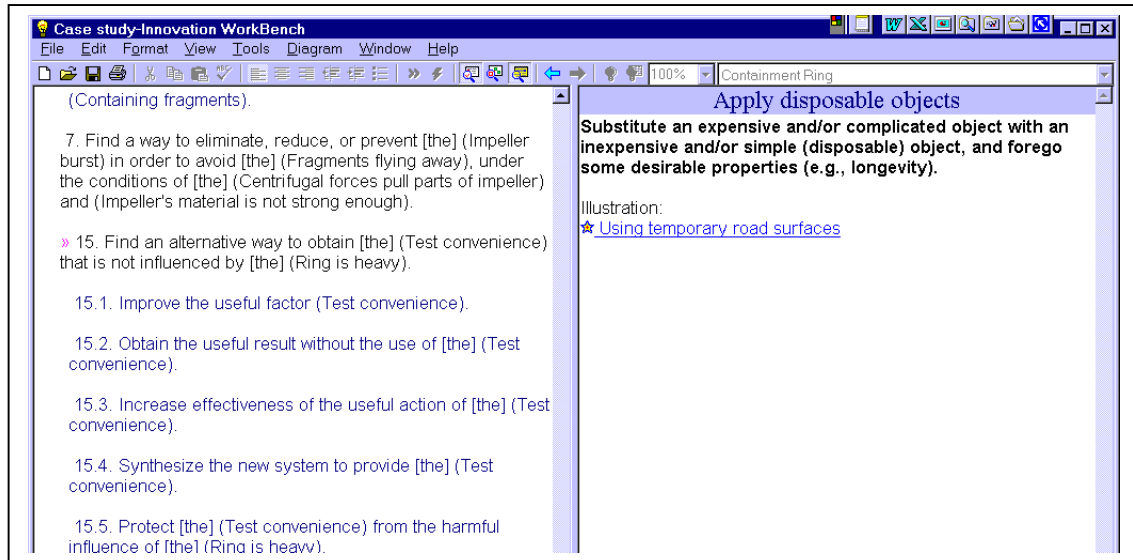
The screenshot shows the 'Case study-Innovation WorkBench' interface. The left pane displays a list of operators for 'Make an object dismountable (module principle)', including: 5.3. Increase effectiveness of the useful action of [the] (Containing fragments). 7. Find a way to eliminate, reduce, or prevent [the] (Impeller burst) in order to avoid [the] (Fragments flying away), under the conditions of [the] (Centrifugal forces pull parts of impeller) and (Impeller's material is not strong enough). 15. Find an alternative way to obtain [the] (Test convenience) that is not influenced by [the] (Ring is heavy). 15.1. Improve the useful factor (Test convenience). 15.2. Obtain the useful result without the use of [the] (Test convenience). 15.3. Increase effectiveness of the useful action of [the] (Test convenience). 15.4. Synthesize the new system to provide [the] (Test convenience).

The right pane is titled 'Make an object dismountable (module principle)' and contains the following text: 'Try to make your object dismountable. If possible, assemble your object (partially or completely) out of existing, standard modules. Illustrations: ☆ Gutenberg's invention, ☆ Modular truck, ☆ Standardizing machine parts'.

See idea # 1: Make the ring as an assembly from light parts that are easy to move for testing.

¹ This direction has been addressed in a limited fashion as we do not have detail information about the test procedure.

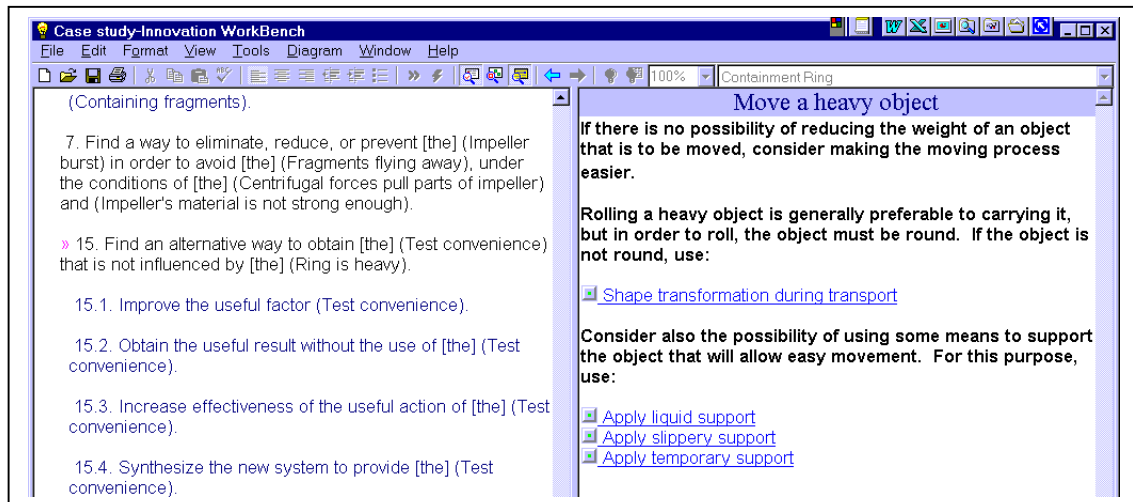
Operator: Apply disposable objects



Idea # 30

Disposable ring – consider that the ring will be destroyed while absorbing all the energy of the fragments (similar to idea # 3).

Operator: Move a heavy object



Idea # 31

Consider various types of support while transporting the ring.

Operator: "Retain the available"

The screenshot shows a software interface titled "Case study-Innovation WorkBench". The main window displays a problem statement: "(Containing fragments). 7. Find a way to eliminate, reduce, or prevent [the] (Impeller burst) in order to avoid [the] (Fragments flying away), under the conditions of [the] (Centrifugal forces pull parts of impeller) and (Impeller's material is not strong enough). 15. Find an alternative way to obtain [the] (Test convenience)".

Below the problem statement is a window titled "Jacking-up cargo containers" which contains an illustration of a truck with a crane lifting a container. The text below the illustration reads: "Cranes are ordinarily used to load large cargo containers onto trucks. If the trucks are designed with minimum clearance between the truck floor and the road, the containers can be pushed onto the truck after being lifted by a jack. This is simpler and less expensive than using cranes, and the trucks can accommodate larger containers. A disadvantage is a more complicated truck wheel design."

On the right side of the interface, there is a panel titled "'Retain the available'" which contains the following text: "Consider applying the 'retain the available' principle: if your object has some desirable condition or property (e.g., temperature, electric/magnetic field, interrelation or orientation with respect to the ground), any manipulation of the object should be performed such that this condition or property is preserved." Below this text are two links: "Jacking up containers" and "Maintaining part orientation".

Idea # 32

Learn in detail the process of transportation and look for the ways to reduce the number of liftings of the ring.

List and categorize all preliminary ideas

Idea # 1: Make the ring as an assembly made of light-weight parts that are easy to move for testing purposes.

Idea # 2: Provide high airflow with low rotational speed of the fan. Perhaps utilize several slow fans instead of one that rotates quickly.

Idea # 3: Utilize a "weak" ring that will absorb energy as it is destroyed.

Idea # 4: Perform testing without removing the ring.

Idea # 5: Reduce the mass of the fragments to reduce damage.

Idea # 6: Vary the thickness of the ring tube, reducing the thickness where permissible.

Idea # 7: Introduce preliminary stress. For example, use additional rings which have been pressure-fitted to create a force directed toward the inside of the ring.

Idea # 8: Use thermal treatment to harden the ring material.

Idea # 9: Use special reinforcing threads (fibers) such as those found in bullet-proof vests.

Idea # 10: Replace the ring with an airbag that inflates when the impeller bursts.

Idea # 11. Make a thin ring that has reinforcing ribs. If the ribs are placed on the internal surface of the ring, flying fragments will lose much of their energy smashing into the ribs.

Idea # 12: Make the ring corrugated in two planes.

Idea # 13: Determine where the ring usually breaks and reinforce those places.

Idea # 14: Internal ribs with sharp edges can counteract flying fragments, breaking them into smaller pieces.

Idea # 15: Use a multi-layer ring: additional strengthening rings, rings having different hardness and elasticity, rings which have a gap in between them, filling the gap with an energy-absorbing material.

Idea # 16: Make the ring out of separate layers so that if cracks develop inside they will not spread.

Idea # 17: Use metal-concrete or some other composite material.

Idea # 18: Create inner stresses inside the ring. This can be done using wiring, banding, double ring structure, etc.

Idea # 19. Change the ring thickness or strength or other containment capabilities the moment the impeller bursts.

Idea # 20. Explode the ring the moment the impeller bursts. Use the explosion wave to create a counteracting force.

Idea # 21. Disintegrate the fragments.

Idea # 22. Utilize special geometrical shapes to create traps for the fragments. For example, make the ring in the form of spring.

Idea # 23. Create a combination of pressurized air and liquid to counteract the fragments.

Idea # 24: Create a safe pathway for the fragments.

Idea # 25. Introduce strong fibers in the impeller blades that are capable of holding the fragments after the impeller bursts.

Idea # 26. Use foam or foam-like material to absorb energy. Apparently, we need a special type of foam such as metal foam. We can also consider other fillings that can absorb energy (see idea # 3).

Idea # 27. Define the least dangerous directions and redirect the fragments in these directions.

Idea # 28. Distribute the harmful energy between more of the fragments (see also ideas # 7 and 21: reducing energy/mass of the fragments).

Idea # 29. Create a special pathway (spiral) to trap the fragments and to reduce their energy while traveling through the spiral route (see ideas # 22 and 24). Also, see idea # 26: absorb the energy.

Idea # 30. Disposable ring – consider that the ring will be destroyed while absorbing all the energy of the fragments (similar to idea # 3).

Idea # 31. Consider various types of support while transporting the ring.

Idea # 32. Learn the details of the transporting process and look for the ways to reduce the number of liftings.

We can categorized the obtained ideas into the following groups:

1. Strengthening the ring via

a) changing the ring material structure:

- creating inner stresses (wiring, banding, press-fit) (#18, 7)
- introducing special reinforcing threads (fibers), using metal-concrete or other composite materials (# 9, 17, 25)
- special thermal treatment for hardening the ring material (# 8)
- using a multi-layer ring with layers with different properties (elasticity, hardness, gaps filled with energy-absorbing materials) (# 15)

b) changing the ring's shape:

- vary the ring thickness to best accommodate the situation (# 6,13)
- create various reinforcing ribs (# 11)
- use two-plane corrugations (# 12)

2. Increasing the ring's energy-absorbing properties via

a) changing the material structure:

- using foam and/or foam-like materials (metal foam, honeycomb, wiring, brushes) (#3, 23, 26, 30)
- using a multi-layer ring with layers capable of moving relative to one another to absorb extra energy

b) changing the ring's shape:

- spiral or other traps that can slow down the fragments (#22)

3. Reducing the mass/energy of the flying fragments to reduce damage and allow the ring's mechanical strength to be lowered via

- changing the ring's material structure to make it capable of breaking into smaller pieces (# 5, 21,28)
- introduce ribs with sharp edges capable of breaking fragments into smaller pieces (# 11,14)

4. Improve testing convenience, including:

- perform the test without removing the ring (# 4)
- make the ring dismountable and transport parts of the ring rather than the whole thing (# 1)
- consider various types of special support during ring transport (# 31)

5. Strengthen the impeller blades to eliminate the need for the ring (#25)
6. Define or create a safe pathway for the fragments (# 24, 27, 29)
7. Change the principle of operation of the ring, including:
 - replace the ring with an airbag that inflates the moment the impeller bursts (# 10) or change its thickness (# 19)
 - explode the ring to create a counteracting force (# 20) and/or break the fragments into smaller pieces
8. Replace the impeller with a safer method of providing air (# 2)

Develop Concepts

The screenshot displays the 'Case study-Innovation WorkBench' software interface. The window title is 'Case study-Innovation WorkBench' and the menu bar includes 'File', 'Edit', 'Format', 'View', 'Tools', 'Diagram', 'Window', and 'Help'. The toolbar contains various icons for navigation and editing. The main content area is divided into two panes. The left pane shows a list of tasks: '15.6. Apply universal Operators to provide the useful factor (Test convenience).', '15.7. Consider resources to provide the useful factor (Test convenience).', '2. List and categorize all preliminary ideas', 'Develop Concepts', '1. Combine ideas into Concepts', '2. Apply Lines of Evolution to further improve Concepts', 'Evaluate Results', '1. Meet criteria for evaluating Concepts', '2. Reveal and prevent potential failures', and '3. Plan the implementation'. The right pane is titled 'Develop Concepts' and contains the following text: 'While working with the **Operators** you have likely developed many ideas. Seldom, however, does a single idea solve the entire problem – more often, the combination of several ideas is needed.' Below this, it states: 'This stage of the problem-solving process is devoted to improving your ideas and combining them into **Innovation Concepts**.' and lists two sub-points: '1. [Combine ideas into Concepts](#)' and '2. [Apply Lines of Evolution to further improve Concepts](#)'.

Combine ideas into Concepts

Combine ideas that perform the same function in different ways

The screenshot shows a software interface titled "Case study-Innovation WorkBench". The main window displays a document with the following content:

15.6. Apply universal Operators to provide the useful factor (Test convenience).

15.7. Consider resources to provide the useful factor (Test convenience).

2. List and categorize all preliminary ideas

Increasing missile accuracy

Because artillery shells have high trajectories and high muzzle velocity, they can be accurately delivered to a target. Atmospheric conditions like wind, pressure, and humidity have little effect on the path of the shells. The ballistic range for these shells is determined by the energy accumulated when they are fired, and it can be extended by increasing the firing charge. In contrast, the accuracy of unguided missiles is relatively poor since they leave the launcher at lower speeds.

To improve both accuracy and range, combining two approaches was considered:

The diagram shows two scenarios of projectile motion. On the left, an artillery shell is launched at a high angle, following a parabolic trajectory that reaches a high peak before descending to a target. On the right, a missile is launched at a lower angle, following a more direct, slightly curved path to the same target. The shell's path is significantly higher and more curved than the missile's path.

The comparison of approaches shows that:

- The shell has better accuracy
- The missile has better range

The range is considered as "functional" feature:
The shell is the "recipient" of the resources

The right-hand pane of the software displays a title: "Combine ideas that perform the same function in different ways". Below the title is a paragraph: "The approach of combining the ideas that perform the same function in different ways assumes that each idea has its own advantages and disadvantages. As a result of combining, the new idea should have all these advantages and no disadvantages." Below this is a list of steps to accomplish this:

1. Select two ideas that resolve the same sub-problem in different ways.
2. Compare these ideas; each has its own advantages.
3. Consider the idea that has better functional features as the "source of resources"; the other idea is the "recipient of resources."
4. Determine the elements that provide better functionality of the "source" idea.
5. Apply these elements to the "recipient."
6. Consider if some elements of the "recipient" can perform functions of the newly-applied elements, and simplify the system.
7. The best possible result is that the new system consist of elements of the "recipient" and have the features of the "source."

Illustration: ☆

Step 1. Select two ideas that resolve the same sub-problem in different ways.

Idea # 17 (Use metal concrete or other composite materials) and idea # 11 (make a thin ring with reinforcing ribs) provide the same function (strengthening) in different ways – changing structure (#17) and changing shape (# 11).

Step 2. Compare these ideas; each has its own advantages.

Idea # 11 is preferable from the main function point of view because it can provide greater strength. However, it is not easy to make ribs from the steel. The advantage of idea # 17 is that composite materials are easy to shape.

Step 3. Consider the idea that has better functional features as the "source of resources"; the other idea is the "recipient of resources."

We select idea # 11 as the "source of resources"

Idea # 17 is the "recipient of resources"

Step 4. Determine the elements that provide better functionality of the "source" idea.

The element providing better functionality is a steel tube.

Steps 5-7. Apply these elements to the "recipient."

We can combine two ideas having a steel tube with ribs made from a composite material.

Apply Lines of Evolution to further improve your Concepts

Case study-Innovation WorkBench

File Edit Format View Tools Diagram Window Help

15.6. Apply universal Operators to provide the useful factor (Test convenience).

15.7. Consider resources to provide the useful factor (Test convenience).

2. List and categorize all preliminary ideas

Develop Concepts

1. Combine ideas into Concepts

2. Apply Lines of Evolution to further improve Concepts

Evaluate Results

1. Meet criteria for evaluating Concepts

2. Reveal and prevent potential failures

3. Plan the implementation

Apply the Lines of Evolution

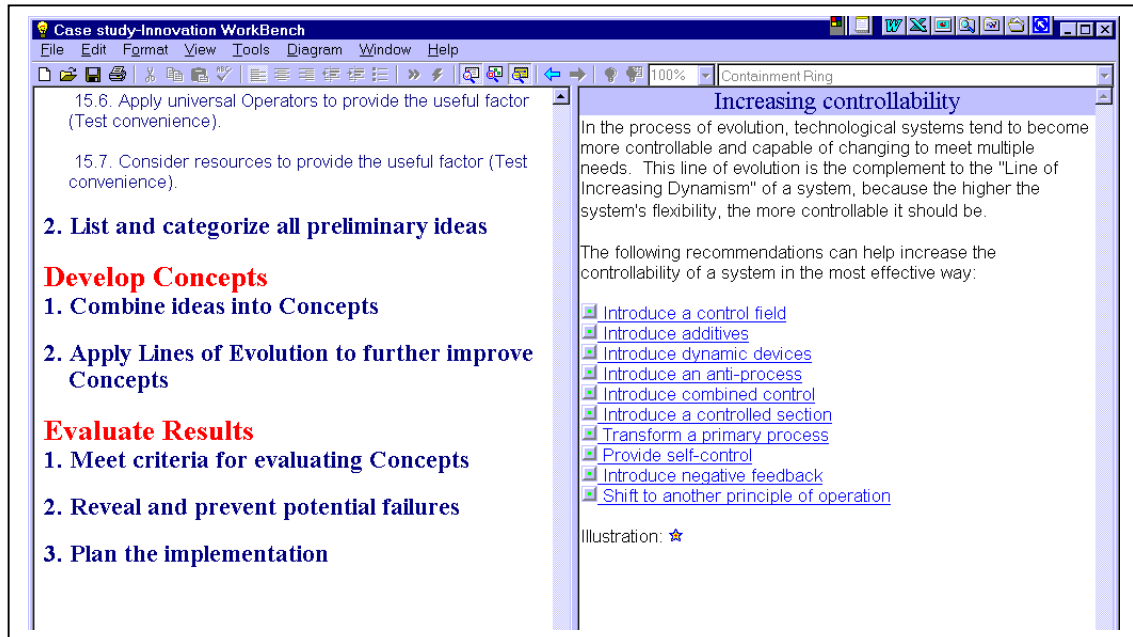
You can further improve your Concepts utilizing selected Patterns of Evolution.

The **Patterns of Evolution** represent a compilation of trends that document strong, historically-recurring tendencies in the development of man-made and natural systems. A Pattern usually contains **Lines of Evolution** that describe in greater detail typical sequences of the stages (positions on a Line) that a system follows in the process of its natural evolution. Once these positions are known, the system's current position(s) on a line can be identified, and the possibility of transitioning to the next position (s) can be assessed. In some situations it may be obvious how this transition should be made. In other cases it will be helpful to apply the following recommendations, called **Operators/Lines**:

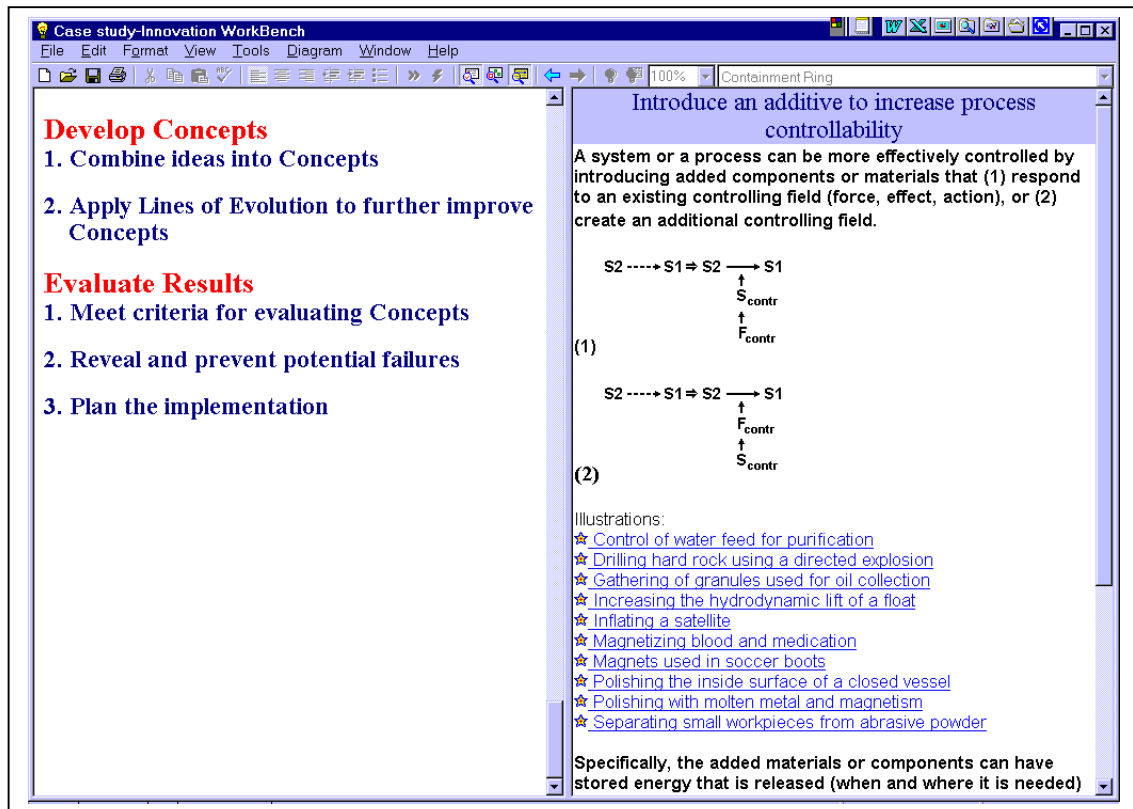
- [Increasing ideality](#)
- [Building bi- and poly-systems](#)
- [Segmentation](#)
- [Developing a substance's structure](#)
- [Dynamization](#)
- [Increasing controllability](#)
- [Element universalization](#)

A substantial number of the obtained ideas have already included features recommended by most of the patterns/lines above. For example, the idea of a multi-layer ring is in accordance with the patterns Building bi-and poly-systems and Segmentation; the idea of using composite materials fits the pattern Developing a substance's structure; ideas related to replacing the ring with an airbag or exploding the ring fit the pattern of Dynamization.

It might still be interesting, however, to consider the set of Operators/Lines entitled Increasing controllability.



Operator: Introduce an additive to increase process controllability



Operator: Introduce a controlled section

The screenshot shows the 'Case study-Innovation WorkBench' interface. The left pane contains a list of operators under 'Develop Concepts' and 'Evaluate Results'. The right pane is titled 'Introduce a controlled section' and contains the following text:

Introduce a controlled section
Consider replacing a poorly-controlled system or process with a number of components or events. At least one of the components or events should be well controlled.

$$S1 \rightarrow S2 \Rightarrow S1 \rightarrow S2 \rightarrow S3 \rightarrow S4$$

↑

Illustrations:
★ [Safely collapsing a burning building](#)
★ [Sealing with ferromagnetic liquid](#)
★ [Transforming varying light into vibration](#)
★ [Using wood's alloy to level foundations](#)

For example, if a process aims at changing the shape of a structure, consider introducing a weakened member that will give way at the right moment.

For this purpose, use:
★ [Partial preliminary action](#)

Operator: Self-control

The screenshot shows the 'Case study-Innovation WorkBench' interface. The left pane contains a list of operators under 'Develop Concepts'. The right pane is titled 'Self-control' and contains the following text:

Self-control
Consider having the system or process adjust itself to changing operating conditions.

Illustrations:
★ [Controlling long trains](#)
★ [Increasing mold pressure with gas](#)
★ [Jettisoning ballast upon water penetration](#)
★ [Preventing a gas main fire from spreading](#)
★ [Sealing with ferromagnetic liquid](#)
★ [Self-balancing of a flywheel](#)

A pop-up window titled 'Jettisoning of ballast upon water penetration' is visible, containing an illustration of a bathyscaph and the following text:

Jettisoning of ballast upon water penetration

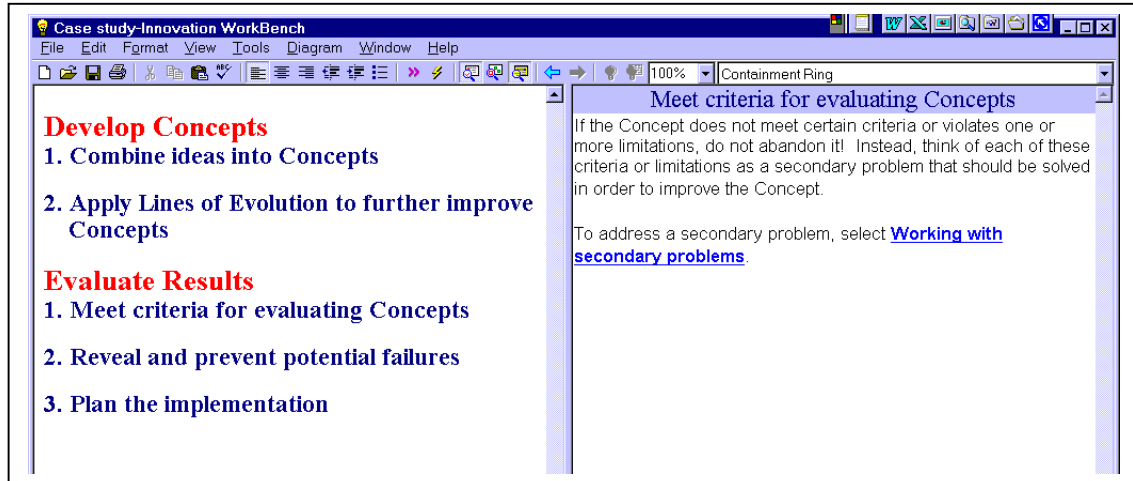
It was essential that the bathyscaph (a navigable ocean-diving vessel designed to reach great depths) include a method for indicating water leaking into the vessel.

The inventor Piccard installed contacts in the lowermost section of the gondola. If the contacts were closed by water, a signal was sent to command the ballast to jettison.

The Operators above allow us to further develop idea # 20 (explosive ring). A controlled section (detonator) and additives (explosives) should be placed in the light tube. The first fragment that will reach the tube will activate the detonator (self-control).

Evaluate Results

Meet criteria for evaluating Concepts



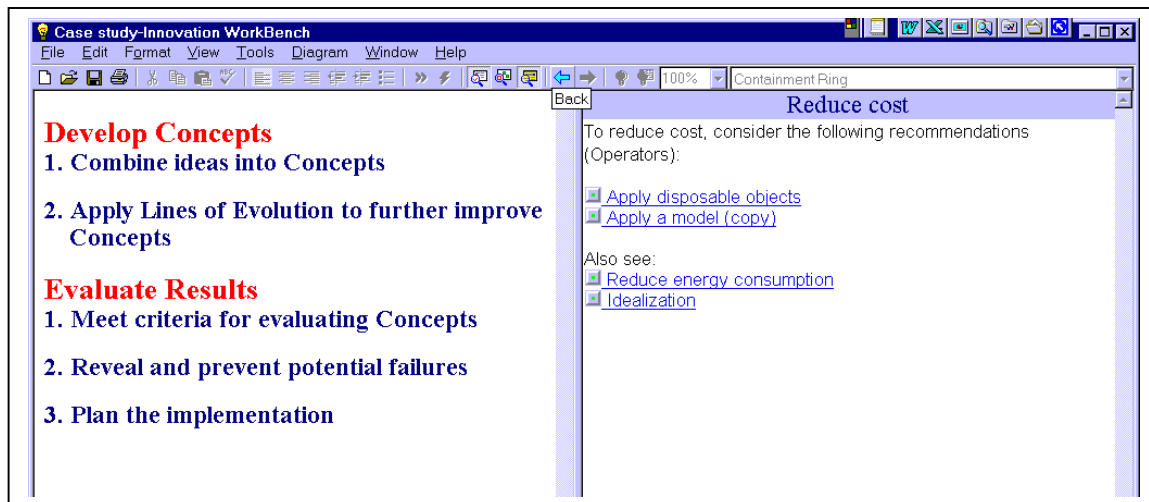
The following ideas were selected:

For short-term: Multi-layer ring; ring with ribs.

For mid-term: Explosive ring.

For long-term: Blades with fibers (wire) inside to keep pieces in place.

The short-term idea of utilizing a multi-layer ring creates a secondary problem – the increased cost associated with manufacturing the different layers and with the final assembly of the ring. We therefore have a secondary problem – reduce cost.



Idealization

The screenshot shows the 'Case study-Innovation WorkBench' application window. The left pane contains a list of steps under 'Develop Concepts' and 'Evaluate Results'. The right pane is titled 'Idealization' and provides a definition of the process, followed by a list of operator recommendations.

Develop Concepts

1. Combine ideas into Concepts
2. Apply Lines of Evolution to further improve Concepts

Evaluate Results

1. Meet criteria for evaluating Concepts
2. Reveal and prevent potential failures
3. Plan the implementation

Idealization

Idealization is a process that targets the **ideal system**, that is, a system that performs a required function without actually existing. Idealization allows you to approach the ideal situation as closely as possible given the available resources and imposed limitations.

To make your system more ideal, consider the following recommendations (Operators):

- [Exclude duplicate elements](#)
- [Use more highly integrated subsystems](#)
- [Exclude auxiliary functions](#)
- [Self-service](#)
- [Exclude elements](#)
- [Consolidation of discrete subsystems](#)
- [Simplify through total replacement](#)

Exclude auxiliary functions

The screenshot shows the 'Case study-Innovation WorkBench' application window. The left pane is identical to the previous screenshot. The right pane is titled 'Exclude auxiliary functions' and provides a definition of auxiliary functions, followed by a list of operator recommendations.

Develop Concepts

1. Combine ideas into Concepts
2. Apply Lines of Evolution to further improve Concepts

Evaluate Results

1. Meet criteria for evaluating Concepts
2. Reveal and prevent potential failures
3. Plan the implementation

Exclude auxiliary functions

Auxiliary functions provide support and/or contribute to execution of the system's main (primary) function(s). In many situations auxiliary functions can be excluded (together with the elements and/or parts associated with their performance) without deteriorating the performance of the main function(s).

To find a way to exclude an auxiliary function, consider the following recommendations (Operators):

- [Exclude correcting functions](#)
- [Exclude preliminary functions](#)
- [Exclude protective functions](#)
- [Exclude housing functions](#)
- [Exclude other auxiliary functions](#)

For measurement/control systems, also see:

- [Eliminate the need for measurement](#)

Operator: Exclude preliminary operations (functions)

Develop Concepts

1. Combine ideas into Concepts
2. Apply Lines of Evolution to further improve Concepts

Combined surface processing of metal components

Surface processing of metal components by shot peening is a widely-used technique. Other techniques include thermal processing – in particular, heating and cooling.

A surface processing method is suggested which combines the processes of cooling and plastic deformation: a high-velocity stream of ice-balls (shot encased in ice) is directed onto a heated steel surface.

To ensure a continuous flow of ice-balls, they are created as they are fed onto the steel. Drops of a liquid are fed directly into the gas flow, which cools the shot to the temperature necessary to produce the desired hardness.

Exclude preliminary operations (functions)

Consider the need for each preparatory operation (function) of your system. Can the primary system function be implemented without first implementing any of the preparatory operations? Or, can any of the preparatory operations be accomplished (perhaps by using a different method) in parallel with the primary system function?

Illustration:
★ [Combined surface processing of metal components](#)

Idea # 33

Instead of manufacturing several layers and assembling them later, use surface hardening of the internal and external surfaces of the ring. Hardening the inner surface will allow the ring to better counteract the fragments. Hardening the outer surface can create additional inner stresses that in turn increase the ring's overall strength. Together, these measures should allow the weight of the ring to be reduced without sacrificing its containment capabilities.

Reveal and prevent potential failures

The screenshot shows the 'Innovation WorkBench' interface. The left pane contains a navigation menu with the following items:

- Develop Concepts**
 - 1. Combine ideas into Concepts
 - 2. Apply Lines of Evolution to further improve Concepts
- Evaluate Results**
 - 1. Meet criteria for evaluating Concepts
 - 2. Reveal and prevent potential failures
 - 3. Plan the implementation

The right pane is titled 'Reveal and prevent potential failures' and contains the following text:

Instead of brainstorming about what non-obvious failures might occur, in I-TRIZ you "invent" possible failures – then find ways to prevent or eliminate them. For this purpose, formulate the problem of inventing the failure using the following template:

There is a Concept called [Concept name and brief description] **for** [Purpose for implementing the Concept]. **It is necessary to produce all possible undesired effects that can occur during the implementation of this Concept.**

Then follow these steps:

1. Describe each stage of Concept implementation.
2. Describe the possible failures of each stage.
3. List all obvious ways to "accomplish" each failure.
4. Consider [weak and dangerous zones](#) as resources for potential failures.
5. Consider [possible failures of devices, objects, etc.](#)
6. Consider [possible harmful impacts](#) on each stage of implementation.
7. Consider [potentially dangerous moments/periods of time](#) during implementation.
8. Consider measures for preventing the failures you have revealed.

7. Consider potentially dangerous moments/periods of time during implementation.

The screenshot shows the 'Innovation WorkBench' interface. The left pane is identical to the previous screenshot. The right pane is titled 'Potentially dangerous moments/periods of time' and contains the following text:

Consider the following as potential resources for failure during any stage of implementation:

- Periods of disturbance in an otherwise monotonous operation/process
- Periods of high general stress
- Periods during which newcomers or visitors arrive
- Periods of high personal stress
- Periods following a catastrophe, failure, etc.
- Test periods, etc.

Idea # 34

According to the checklist, testing the ring can be dangerous itself – for example, reducing the ring's strength can later produce a ring failure. To avoid this problem, it might be preferable to replace the current test procedure with one that utilizes ultrasound, acoustic emission or other "intro-vision" technologies.

Plan the implementation

The following ideas were suggested for testing:

For the short-term: Ring with hardened surfaces; ring with ribs.

For the mid-term: Explosive ring.

For the long-term: Blades with fibers (wire) inside to keep the fragments in place.

Summary

Category	Tool utilized			
	Contradiction Table	Ideation Improver	Ideation IWB	IMC Tech Optimizer ²
Number of Directions (problem statements) offered	3	6	18	
Number of recommendations (Operators) offered	11	44	>100 + >10 groups	
Number of ideas obtained	6	19	34	

² The column will be filled out in the next issue.