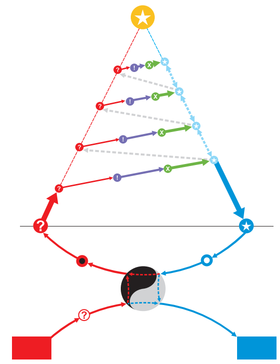
An example of problem solving by

targetInvention technologies

Production of even sheet glass



Solved with the Algorithm of Improving Problem Situations

Problem situation

One company produced even sheet glass for flat monitors. The maximum width of the ready-made glass is 0,7 meter. Equipment for the glass strip production is designed in such a way that liquid glass flows by a flat flow along a special long guide (ISO-pipe) and hardens forming a glass strip. The strip is moving downwards accelerated by two roller pairs. Further on the solidified glass strip is cut into pieces of the appropriate size. Later, the glass is packed into boxes.

The company started the production of large-sized even glass sheets with the width of about 1,5 meters. The necessary equipment analogous to the previous one was designed. The experiments showed the quality of the glass to be satisfactory according to all the parameters except the one. So, the glass surface appeared not to be even enough.

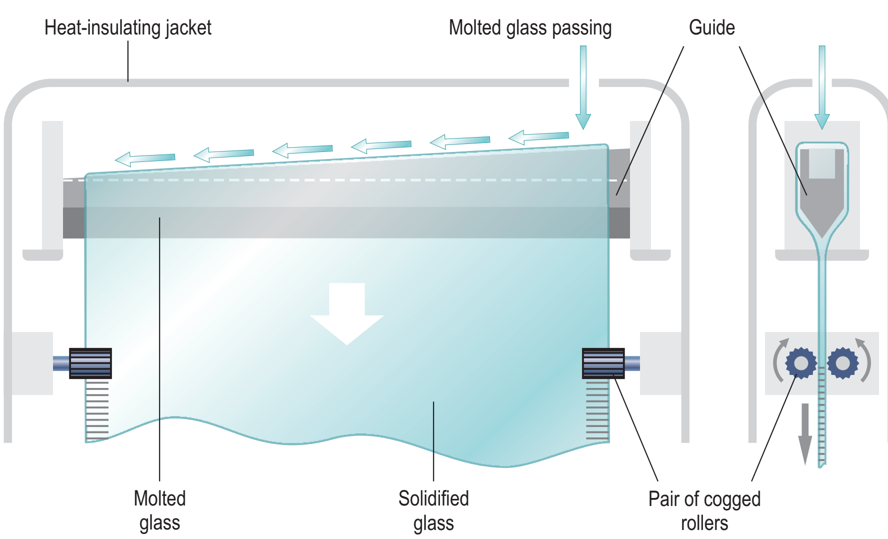
Let's generalize the problem situation information obtained from the customer.

Key product of a machine. Thin glass sheets

Technological process. Melted glass flows downwards and solidifies forming a strip of 1,5 meters wide. The strip is cut into pieces of the appropriate size.

Undesirable effect. The glass obtained is uneven.

Step 1.1. Reveal a problem area

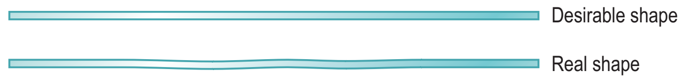


Substep A. Describing machine design and functioning

The main part of the machine is the guide. At the bottom it has a wedge shape, at the top there is a longitudinal groove. The guide is covered by a heat-insulating jacket. Liquid glass passes through the nozzle to the guide, distributes all over it forming a strip stream and flows downwards solidifying gradually. Below the guide there are two pairs of cogged rollers which accelerate the moving of the glass strip being formed. Each pair of rollers is brought into motion by the electromotor via the reducer. Further on, both a cutting and a packing modules are installed (they are not shown at the figure).

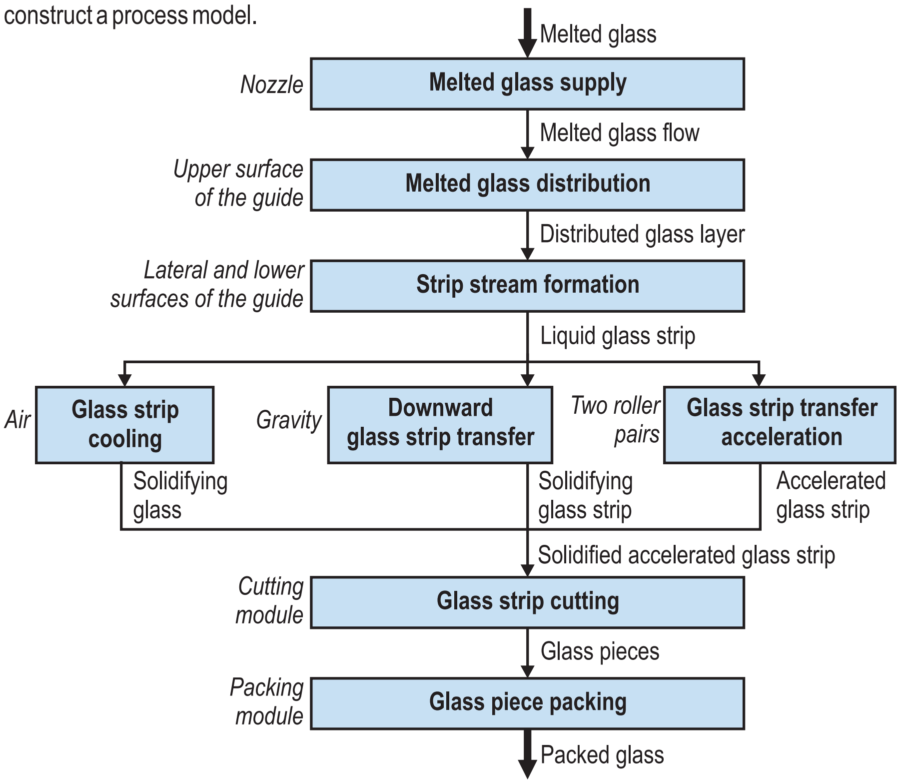
Substep B. Specifying a harmful product

Glass deformation has constant character (longitudinal creases). Creases are a harmful product.

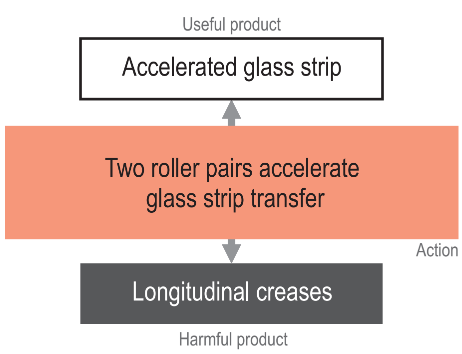


Substep C. Determining a probable conflict zone

In order to define the moment of the crease appearance let's go into details of the machine construction for glass production and the organization of the technological process. Let's construct a process model.



Creases can't appear when the glass has finally solidified. They can't appear in the liquid glass either. So, we should consider that part of the process when glass is in the intermediate state. This is the stage when the glass strip is moving downwards accelerated by the rollers and is gradually solidifying. Consequently, a problem action is acceleration of glass strip transfer.



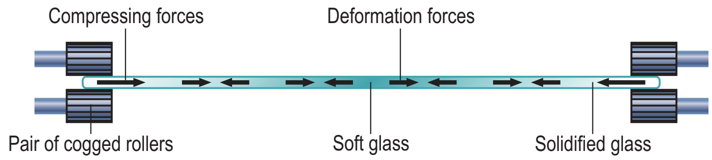
Step 1.2. Define a conflict

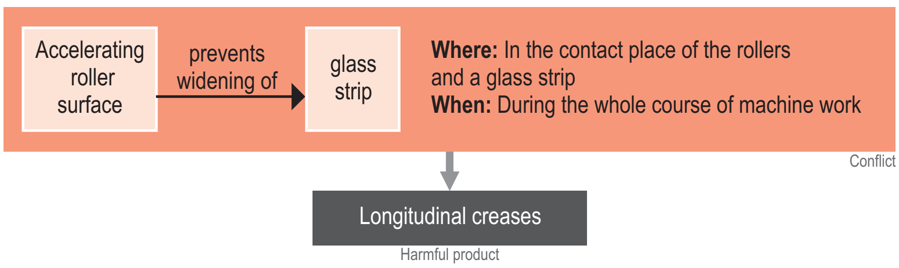
Substep A. Describing a conflict

It's necessary to find out what the harmful action is which creates creases on the glass. So, let's get into the essence of the occurring processes.

The solidifying glass strip is creased for some reason as if pressed at sides by some unknown force. The analysis showed the middle part of the strip to crease more than its lateral parts. Such phenomenon can occur if the accelerating rollers start compressing the glass strip being still soft and reducing its width (as a piece of cloth is creased when compressed). But the rollers are placed rather accurately so that their position is unchanged. So, what seems to be the cause of it?

Any heated object, glass strip included, cools down not uniformly. The lateral parts of the strip are the first to cool down while the middle remains hot and soft a bit longer. Due to it the glass strip undergoes complex internal deformations, expansion included. And rollers prevent this expansion.





Substep B. Evaluating the necessity of removing a conflict

Undesirable effect, i.e. uneven glass, causes glares and image distortions on the screen. This quality loss of the end product is unacceptable and the conflict must be eliminated.

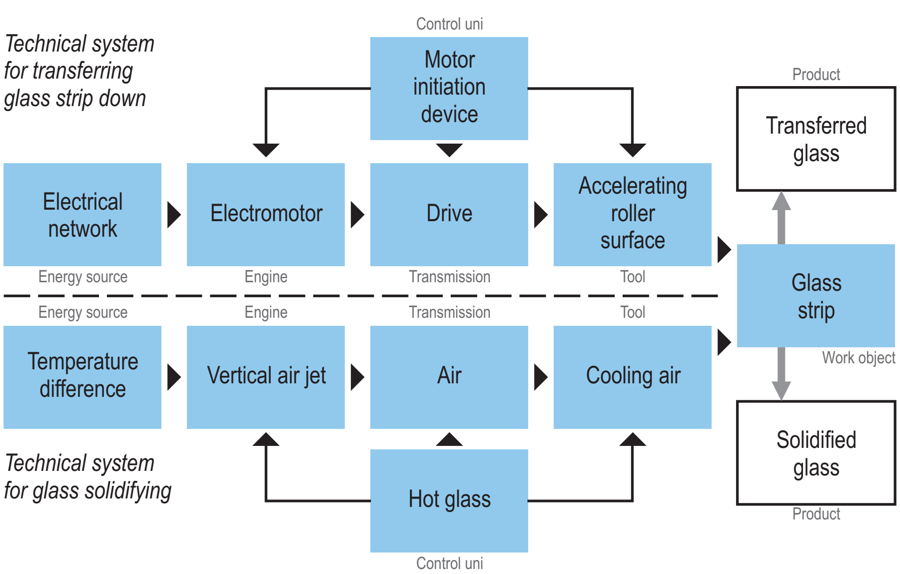
Step 1.3. Investigate the problem area

Substep A. Determining the conflict character

The useful action, i.e. the glass strip acceleration by the rollers is accompanied by the harmful one (a barrier for the glass free expansion). This is the conflict interaction of type 3, i.e. a harmful action which accompanies a useful one.

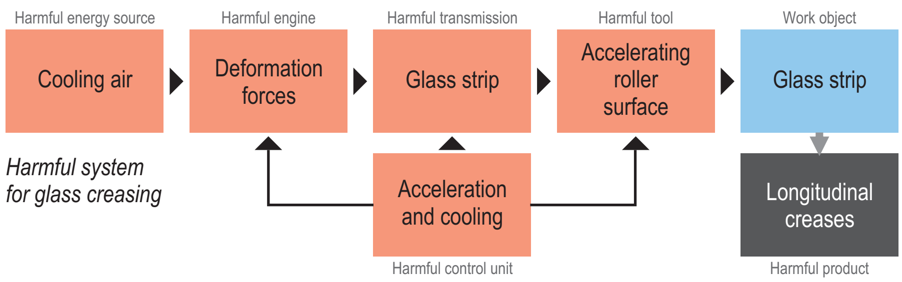
Substep B. Modeling a useful system

In the given case the work object undergoes a complex action. One useful system is aimed at downward moving of the glass strip while the other one is aimed at its solidifying. In order not to lose the necessary details let's construct the models of both useful systems.
The tool that makes the glass strip move downwards is the accelerating roller surface. The rollers are brought into motion by an electromotor (engine). The drive transmits the energy to the rollers. The energy is supplied into the system from electricity network. The system is manipulated by the device used for switching on the motor.
The tool providing glass solidifying is the cooling air contacting the glass. The engine is the vertical air current providing constant supply of new cold air. Transmission is the air. The energy for operation is provided by the temperature difference (the heating air comes upwards while the cooling air is drawn from below). The control unit here is the presence of the heated object, i.e. hot glass, in the air mass.



Substep C. Modeling a harmful system

Let's check if we understood the nature of the conflict correctly. Let's construct the model of a harmful system which causes glass creasing. The work object is the glass strip. A harmful tool is the accelerating roller surface. The harmful engine is the deformation stress of the glass strip at solidifying. This stress is transferred to the tool via the glass strip itself (transmission). The energy source is the cooling air. The system performance is controlled by cooperate actions: acceleration of the glass by the rollers and its cooling (control unit).



Conclusion: the causes of the conflict appearance lie in the fact that there occurs some expansion stress in the glass and the rollers prevent free expansion of the glass strip.

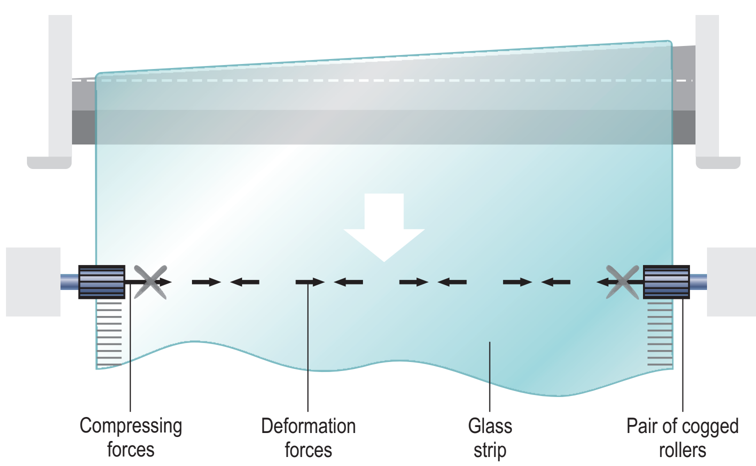
Step 1.4. Formulate problems

Substeps A and B. Propounding hypotheses. Selecting promising hypotheses

In order to eliminate the strip creasing we should find the way to break "the harmful system". The glass strip (transmission) can't be removed and is unlikely to be transformed. Stress appearing at the solidifying glass deformation (the engine) is stipulated by natural laws and can't be eliminated. Cooling air (energy source) is necessary for the work of the useful system. The only component of the harmful system to be transformed is the roller pairs (tool).
Hypothesis 1. The conflict can be eliminated unless the rollers prevent the free expansion of the strip width.

Substep C. Formulating problems on the basis of the hypotheses

Description of circumstances: At producing glass sheets a flat flow of glass melt is moving top-down and gradually solidifies. At cooling and crystallization of glass there appears some internal stress which causes expansion of the glass strip. Cogged accelerating rollers control the strip edges and prevent the strip from free expansion. This causes glass creasing.
Indication of the conflict: Accelerating roller surface prevents the glass strip widening.
Conflict elimination hypothesis: The conflict can be eliminated unless the rollers prevent the free expansion of the strip width.
Question: How to provide a free width increase of the glass strip?



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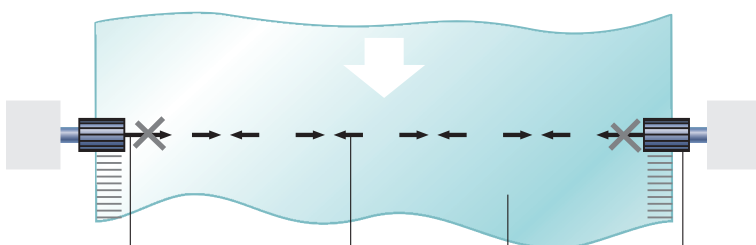
Iteration 1. Work with a formalized problem model

Step 2.1. Construct a formalized problem model

Short formulation	A moving glass strip is trying to expand when solidifying. Accelerating rollers prevent it. It's necessary to provide the free expansion of the glass strip.			
Operational zone	Rollers and a part of the glass strip between them.			
Resources	**Substance resources**	**Field resources**	**Time resources**	**Spatial resources**
	Rollers Melted glass Solidifying glass Ready-made glass strip Technological paths along the strip edges Air Jacket Guide Electromotor Drive	Gravity Thermal field Internal stress in the glass Air curent Electricity	All production time	Area around the rollers
Restrictions	It is prohibited: to change the temperature due to the conditions optimized; to create vibrations; to create a shock load.			



Step 2.1.1. Transform a formalized problem model into a solution model

How to create such conditions for the strip to expand freely in lateral directions? The most reliable method is to remove the component with prevents this, i.e. the accelerating rollers.

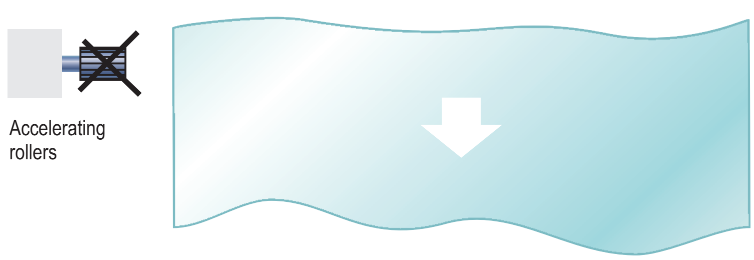
Solution model 1a
To remove the rollers from the construction.

Step 2.1.2. Formulate requirements to a resource

As the component to be transformed is obvious, the list of requirements to the resources isn't needed.

Step 2.1.3. Generate a preliminary solution

Preliminary solution 1a
To remove the rollers from the construction of the equipment for glass production.



Advantages. The glass strip is not deformed.
Disadvantages. As rollers don't accelerate the glass strip while it is moving downwards, the productivity decreases unacceptably.

This solution is invalid. Let's continue working with the problem using the given solution as the base for formulating a technical contradiction.

Iteration 2. Work with a two-parameter problem model

Step 2.2. Construct a two-parameter problem model

In the previous solution we gained the glass strip to be more even, i.e. we improved the "Glass strip form" parameter. But simultaneously, the productivity has decreased.

Improving parameter "Glass strip form" causes inadmissible worsening of parameter "Productivity".

Step 2.2.1. Transform a two-parameter problem model into a solution model

Using Althsuller's Matrix we find the recommended principles to resolve this contradiction.
Principle 17. Dimensionality change
Principle 26. Copying
Principle 34. Discharging and recovering
Principle 10. Preliminary action

The recommendation of principle 17 can be used in directing the force applied to the strip, i.e. to direct force not only downwards but also to the sides. Principle 34 didn't help but principles. 26 and 10 suggest two ideas which could intensify and develop the preceding solution model.

Solution model 2a
To direct the force from the accelerating rollers not only downwards but also to the sides.

Solution model 2b
To provide lateral forces by introducing a copy of some component.

Solution model 2c
To place the components stretching the glass strip prior to the pairs of accelerating rollers.

Step 2.2.2. Formulate requirements to a resource

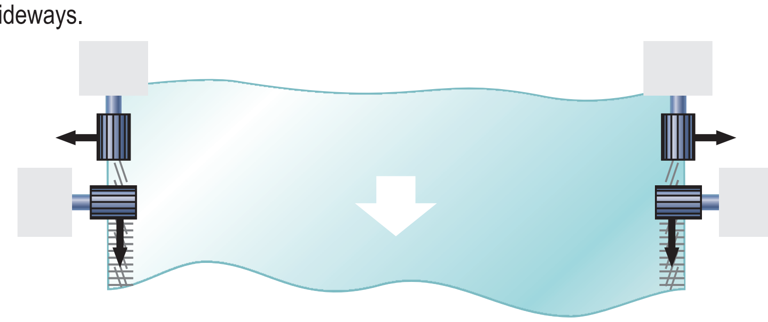
To fulfill these solution models we need some resource. Let's make a list of its requirements.

Action and its peculiarities	To stretch the glass strip widthway.
Ideal Final Result	Rollers and the glass strip, without any additional devices, provide strip stretching widthway.
Place	Prior to the pairs of accelerating rollers (according to Solution Model 2c)
Time	Constantly
Restrictions	No
Additional requirements	No

Step 2.2.3. Generate a preliminary solution

All the solution models of this iteration can be united in one preliminary solution:

Preliminary solution 2a.
To place an additional analogous pair of rollers prior to each main pair of accelerating rollers. To adjust additional rollers so that their axes should be parallel to the direction of the strip moving. So, the roller rotations would create the force stretching the glass strip sideways.

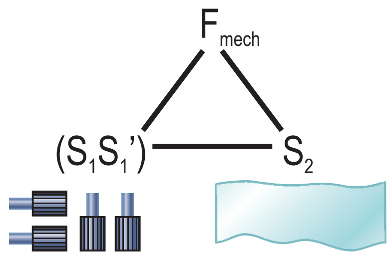


Advantages. Glass strip deformation is eliminated.
Disadvantages. Introduction of the additional drive complicates the equipment. It's difficult to coordinate the work of both longitudinal and transverse rollers.

Iteration 3. Work with a structural problem model

According to Solution 2a four pairs of rollers, two pairs at each strip side, are used to move the strip downwards and stretch it sideways. Two pairs have a horizontal rotation axis, the other ones having a vertical rotation axis. The construction appears to be complex. Let's try to improve this system variant on Iteration 3.

Step 2.3. Construct a structural problem model



Let's construct a Su-Field problem model.
Work object (S_2) – a glass strip.
Tool (S_1) – roller pairs. The tool is complex, so let's mark it as S_1S_1'.
Substances interact via a mechanical field F_{mech}.
Interaction is normal.

Step 2.3.1. Transform a structural problem model into a solution model

It is necessary to simplify the system construction represented by Su-Field. We should find the appropriate standard in the system of standard solutions.
We have a full Su-Field without any harmful interaction, so class 1 will not be taken into consideration. This is not a measurement problem, so class 4 isn't taken into account either. Class 2 standards suggest complicating and forcing Su-Fields but the given Su-Field is already complex. So, only class 3 remains.
Class 3 contains two standards describing Su-Fields which contain a polysystem (we have four pairs of rollers, which corresponds to a notion of a polysystem).

3.1.3. Increasing the difference between elements of bi-and poly-systems. Efficiency of bi-and poly-systems increases at growing the difference between the system elements: from similar elements to elements with shifted characteristics and then to different elements and inverse combinations such as "element and anti-element".

Our case corresponds to the variant "elements with shifted characteristics" (different directions of the rollers). Consequently, we should pass to different elements: the stretching function is fulfilled not by the roller but by another component.

Solution model 3a
To substitute the stretching roller by another component.

3.1.4. Trimming of bi- and polysystems. Efficiency of bi-and polysystems increases at their trimming and moreover due to the removal of auxiliary parts. A completely trimmed bi-and poly-systems again become monosystems.

According to this standard we should reduce the number of components, for example, unite the rollers with different direction axes or some of roller parts.

Solution model 3b
To perform both longitudinal and transverse strip movement only by two roller pairs.

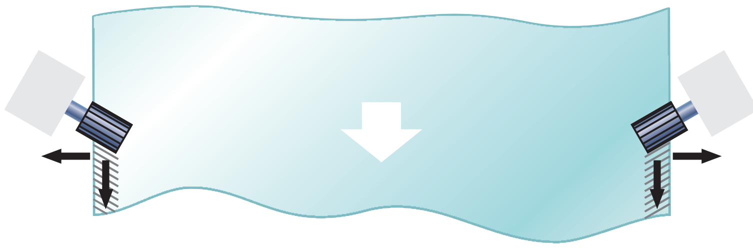
Step 2.3.2. Formulate requirements to a resource

Action and its peculiarities	To stretch and accelerate the glass strip.
Ideal Final Result	Two roller pairs without any additional devices provide accelerating and stretching widthway of the strip.
Place	Where rollers contact the strip
Time	Constantly
Restrictions	No
Additional requirements	No

Step 2.3.3. Generate a preliminary solution

Solution model 3a isn't taken into account as it doesn't presuppose the system simplification. According to solution model 3b it is necessary to use only the rollers themselves without introducing any additional components for accelerating and stretching the glass. So, which roller attribute can be used as a resource? First of all, their position.

Preliminary solution 3a.
To place the pairs of accelerating rollers in the leaning position.



Advantages. The glass strip deformation is eliminated. Two motors and reducers (instead of four) are enough to drive the rollers.
Disadvantages. Although the system is obviously simplified, the construction of the drive itself is still complex. The point is that the rollers should be positioned with a lean and this requires the case transformation.

Iteration 4. Work with a two-parameter problem model

Step 2.4. Construct an one-parameter problem model

A physical contradiction is formulated on the basis of the disadvantage from the preliminary solution 3a. The following contradicting requirements are presented to the roller position:

- Roller axes should be placed in the leaning position for the rollers to stretch the glass strip.
- Roller axes should be placed horizontally in order not to complicate the drive.

Step 2.4.1. Transform a two-parameter problem model into a solution model

This contradiction can be resolved by a system transition which presupposes changing the component part state while the whole component remains in its initial state.

Solution model 4a
A roller has a horizontal rotation axis and its working surface has "an inclination" property.

Step 2.4.2. Formulate requirements to a resource

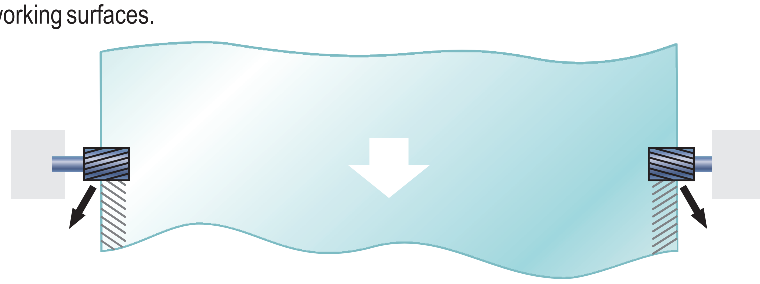
Specifying IFR:

Ideal Final Result	Working surfaces of the rollers without any additional devices provide strip acceleration and stretching widthway.

Step 2.4.3. Generate a preliminary solution

As the resources we can use the peculiarities of the surface relief. In the initial system variant the rollers have tiny cogs situated parallel to the axis. It is possible to change their form.

Preliminary solution 4a.
To place the accelerating rollers horizontally and to serrate the cogs spirally on their working surfaces.



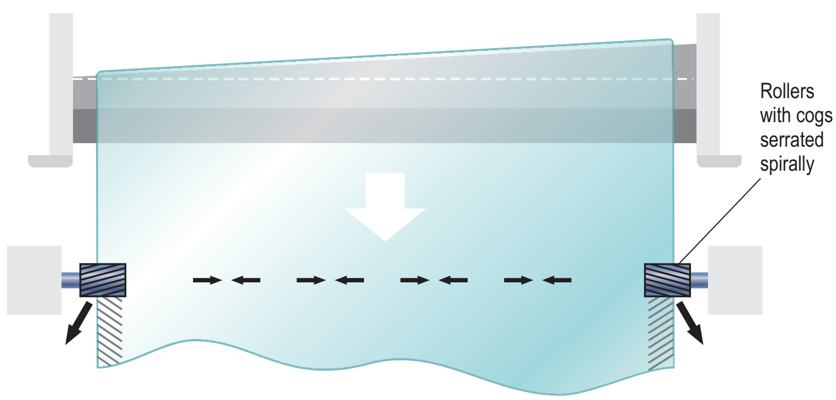
Advantages. The glass strip deformation is eliminated.
Disadvantages. No significant disadvantages

Step 2.6. Construct a final solution

Only solution 4a has no significant disadvantages among all the preliminary solutions suggested. This solution is more ideal one. It doesn't require the introduction of some new components, changes in the construction or in the technological process. The only thing to do is to change the form of the roller working surface. Consequently, this solution can be accepted as final.

Final solution

To substitute accelerating rollers in the existing construction of the equipment for the glass strip production. To place the rollers with the cogs serrated spirally on their working surfaces.



Step 3.1. Compose a technical proposal

The move from the final solution to the technical proposal didn't cause many difficulties. Cog parameters (height, pace, form) have already been optimized on the rollers with the straight cogs. As the stretching force depends on the gradient angle of the spiral roller cogs, we needed some calculations and experiments to optimize this spiral gradient angle.

The proposed solution is technological, i.e. it's necessary only to manufacture new rollers. The drive construction shouldn't be changed. No special equipment is required to manufacture new rollers.

Step 3.2. Estimate conflict elimination

The use of rollers with spiral cogs provides stable glass strip moving downwards with its simultaneous stretching sideways. The obtained glass surface is even. The analysis of the improved situation has fully satisfied the customer. The customer admitted the solution to be almost ideal, i.e. the expenses used to eliminate the drawback are minimal. The problem situation is improved.