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Preliminary communication

Radical Process Improvement by Systematic Approach to Overcome Problems on Custom Glass Eyes Manufacturing

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Abstract: This paper deals with resolving problems with special orders of glass eyes by innovating the process step where the problem occurs. The problem is that when only a few complex eyes are ordered, many prototypes must be made to find glass that fits together and a suitable technique to get the demanded coloring of the iris. The Innovation by Increasing Ideality method based on TRIZ (Theory of Inventive Problem Solving) principles was used to radically improve the process in a way to overcome this problem. A solution was proposed from ideas and proposals generated by the use of the method and TRIZ tools. A new technique of layering resin with paint on the basic crystal eye was found as a possible solution. The technique was tested on several samples and compared with already known and used production methods. The comparison showed that the proposed solution could be used on very complex eyes with better results and lower costs. Also, this proposed technique can be easily improved to get even better results in the future.

Keywords: custom production; glass eyes; process innovation; process improvement; problem-solving; radical changes; TRIZ

1 INTRODUCTION

Production companies want to have better processes, fewer defects, and no problems in production. Many authors discuss efforts to improve the processes by different tools [1-6]. The need for innovation in process improvement is crucial when we want to push the limits of the process to a new level. The importance of process innovation is discussed in many sources [7-9]. Often, process improvement - or innovation and problem-solving are separated. For example, the process is improved, unexpected improvement problems occur, and as a different project, these problems are resolved. Resolution of these problems is often in the way of optimization of parameters. This article discusses an approach to resolving production problems and searching for innovative solutions that radically improve or enhance the production process.

Paper is focused on the problem with difficulties and a high number of defects in the production of special orders in custom production. Customers' demands and expectations are very dynamic, and companies should act flexibly to meet their changing requests [10].

In custom production, many problems occur. One of these issues can be prototyping or mockup-ing of special orders. These prototypes can cost a lot of effort, time, and finance due to more defects and often used special procedures. Prototypes can help overcome the product design constraints [11], but should also help in custom production to lower the number of tries for making demanded results.

The solution for the situation described above can be using systematic creativity known as TRIZ. TRIZ (the Theory of Inventive Problem Solving) is based on the research of hundreds of thousands of patents, where repeatable patterns were discovered. There are repeating generalized problems and repeating generalized solutions for these problems. TRIZ consists of many tools, techniques, and principles that help describe the problem properly and search for highly innovative solutions [12-16].

The Innovation by Increasing Ideality method can be used to resolve process-related problems. It is a method based on TRIZ principles especially designed to lead solvers through the resolving process and use the power of TRIZ even without deep experience with it [17].

This paper aims to use the 3I method to demonstrate the possibility of using the method on the practical problem of producing special orders of glass eyes in a small company from the Czech Republic.

2 METHODS

The Innovation by Increasing Ideality is a method based on TRIZ principles to overcome production-related problems. Instead of resolving the problem, a process or process step, where the problem occurs, is radically changed. That leads to eliminating the problem and a high degree of improvement. The Ideality of the TRIZ is defined by Eq. (1) below.

$$I = \frac{\sum_{i=1}^{n} B}{\sum_{j=1}^{m} H}. \tag{1}$$

where I is Ideality of the technical system, B represents the benefits or positive effects of the system, and H represents the harms or negative effects of the system, n and m are the number of benefits respective harms. In general, the Ideality is increased by either empowering the beneficial effects or reducing the system's harmful effects [18-20].

The TRIZ is a theory consisting of tools, methods, and principles that help solve technical problems or find innovative solutions to improve the product. The main premise is that the real problem is described as a general problem. For the general problem, there is a known general solution. Based on the found general solution, users are trying to find a specific solution to the real problem. This approach helps to find an innovative solution more quickly than just by guessing. Paths from general problems to general solutions are based on the evolution of technical systems found from the research of big amount of patents. The most used principles of TRIZ are Inventive principles to resolve technical contradictions, Separation principles to resolve physical contradictions, Standard solutions, or Trends of Evolution of Technical Systems [21-23].

The Innovation by Increasing Ideality method consists of several steps that lead the solver towards an innovative solution. Firstly the problem and the process are described. Then the purpose of the process is described. The principle of achieving the purpose in the current state is also described. After the problem and process are described, TRIZ tools for increasing ideality can be used. Firstly an Ideal Final Result, or Ideal state, is defined. Then Questions on how to achieve the ideal state are set. After there is known a way to search for the solutions, Trends of the evolution of technical systems with databases of scientific effects are reviewed to search for existing principles on achieving the ideal state. Technical and physical contradictions are determined, and many improvement ideas are collected from the inventive and separation principles. The next step is research in the field of existing technologies. And a generation of initial proposals for the solution. These proposals are reviewed and verified. Only after that, a final solution to the process innovation or problem solution is proposed. The schematic of the systematic approach to resolving the process problems is shown in figure (Fig. 1) below [17].

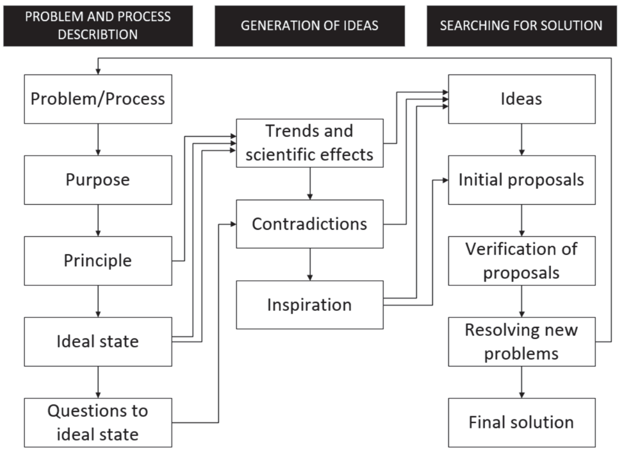

Figure 1 Schematic of Innovation by Increasing Ideality method

2.1 Case Study - Custom Glass Eyes Production

Process of glass eyes manufacturing consists of several operations. All operations are made manually. The whole process can be divided into creating the middle - the pupil, creating and first shaping the eye's "body" - the cornea, coloring and texture of the iris, and final reshaping. Every type of eye requires unique variations of operations and techniques, for example, different pupil shapes and different techniques for creating iris.

Even though it is purely custom production, many types of eyes are demanded repetitively - mostly eyes for taxidermy. That is why these types can be produced in advance. Manual production brings problems. It is almost impossible to create two identical eyes in a row. There are many aspects, such as the shape of the pupil, slightly different coloring or texture, and others. The eyes which are different and have no similar eye to pair with can be stored and used to pair in the next order. This can be applied only to the taxidermy or toy's eyes.

When only one pair of unique eyes is ordered, more eyes must be produced. Firstly technical prototypes are made to test the techniques and glass combination to reduce bubbles, breaks, and other defects. When technique and good glass combination are found, it is still highly unlikely to create two eyes that fit the pair. This is the problem which brings quite a high rate of costs for the special orders. In extreme cases production of such a unique pair of eyes is more expensive than the selling price.

Requests for complex texture and coloring can also be problematic. With used equipment, there are limitations on details that can be made, and during the final reshaping of the eye, the iris coloring can be deformed or twisted, see figure (Fig. 2).

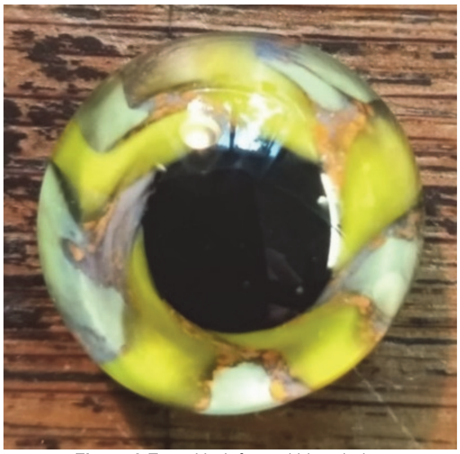

Figure 2 Eye with deformed iris coloring

As an original thought on resolving this, a painting of the crystal eyes was proposed. Painting allows having precise details on the colors of the iris. Unfortunately, it looks unreal because of the lack of 3D relief in the eye. The difference between glass-made iris and painted iris is shown in figures (Fig. 3).

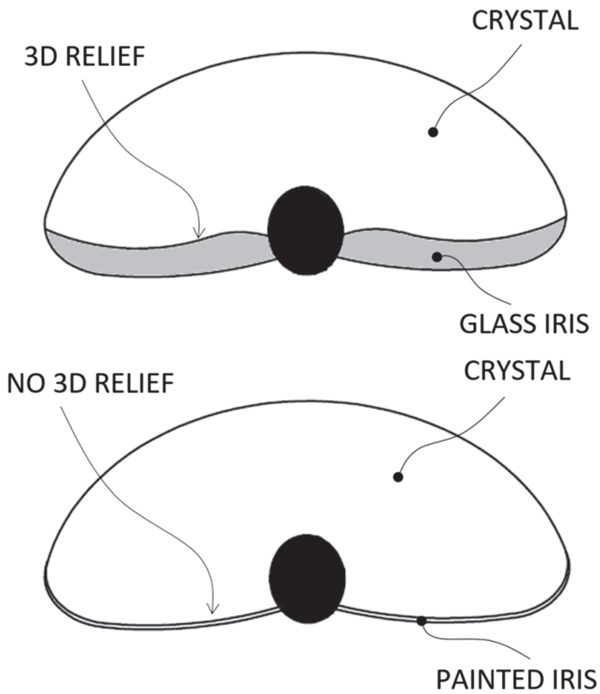

Figure 3 Schematic of an eye with glass-made iris (up); schematic of an eye with painted iris (down).

Another idea for improving the problematic process was to change the supplier of glass. Some suppliers declare the capability of any color combination without breaking. This could reduce defects, but it does not solve the problem. This kind of glass is much more expensive so production would be even more costly in the end.

2.2 Case Study - Application of Innovation by Increasing Ideality Method

The Innovation by Increasing Ideality method was used to overcome the problem described above.

Process problem is defined as a high rate of defects during the prototyping of special requests. The purpose of the process is to create unique glass eyes in a small demanded amount. The principle of the current state is to form the glass in a flame torch and by using molds and different tools. Iris is made by underlaying of colored glass by various techniques. The ideal state is when two identical eyes are created in requested quality on a first attempt. The question of how to achieve the ideal stated is reformulated as: "How to create one pair of eyes in demanded quality on the first try?"

From the evolution trends of technical systems - segmentation, dynamization, transfer from macro to micro, and transfer to supersystem were chosen as interesting ideas. No scientific effects were used.

Several technical contradictions were determined. As parameters for improvement were chosen: 12. Shape, 13. Stability, 29. Precision of manufacturing, and 32. Ease of manufacturing. Parameters that are worsening were chosen: 26. Lost of substance, 27. Reliability, 31. Harmful factors from the object, and 32. Ease of manufacturing. All these parameters were combined to create technical contradictions. A list of inventive principles was generated using the Altshuler's matrix. See the Tab. 1.

Table 1 List of found inventive principles

Number of occurrences	Inventive principle
5	35. Parameter Changes
4	32. Change Optical Properties; 1. Segmentation;
2	40. Composite Materials; 17. Another Dimension;
1	15. Dynamics, Dynamization; 10. Preliminary Action; 36. Phase Transition; 11. Beforehand Cushioning; 4. Asymmetry; 30. Flexible Shells and Thin Films; 23. Feedback; 19. Periodic Action; 22. Blessing in Disguise; 16. Partial or Excessive Action; 27. Cheap Short-living Objects; 34. Discarding and Recovering; 28. Mechanics Substitution; 39. Inert Atmosphere; 26. Copying; 24. Intermediary, Mediator.

A physical contradiction was determined. There is a need to have complex eyes to satisfy customers' requests. Also, there is a need to have simple eyes in order to be easily manufactured. Based on this contradiction, ideas from separation principles can be generated.

As a next step, a list of ideas and inspirations was created. From technical contradictions a list of inventive principles was generated.

The physical contradiction leads to separation. There can be a search for a solution by separation in time, space, or system. The model of the physical contradiction is shown in the figure (Fig.4) below.

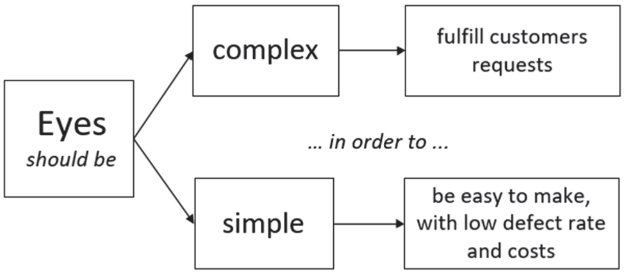

Figure 4 Model of the physical contradiction

Proposals for overcoming the problem should be generated from all the ideas, trends, inventive, or separation principles.

3 RESULTS AND DISCUSSION

As a proposal to solution a new technique was proposed. The solution is inspired by principles such as: Segmentation, Another dimension, Composite materials, and change of optical properties. Also, segmentation in time, space, and principle is used.

To have a simple eye but complex eye, firstly a clear crystal glass eye should be made, then coats of paint and layers of resin should be painted from the backside of the eye. Crystal eye is easy to produce with a low defect rate. By painting, very complex shapes and colors can be achieved. Even if something is wrong, the painting can be corrected during operation. Layers of the resin between paint layers give the 3D effect of the iris relief. Schematic can be seen in the figure (Fig. 5) below.

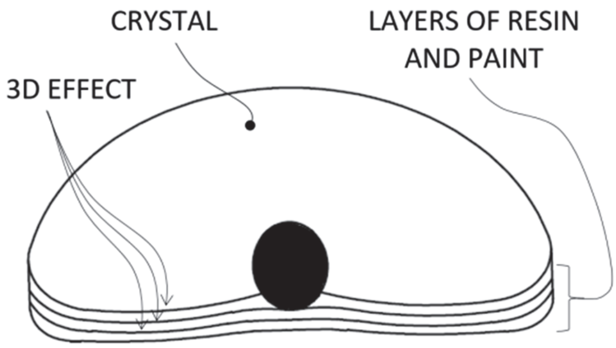

Figure 5 Schematic of the solution based on resin layers

3.1 Verification of Functionality of the Proposed Solution

To verify the usability of the proposed solution real experiment of eye creation by the proposed technique was done. Firstly a relief painting was done on the clear crystal eye. Then, a layer of resin was placed. After the resin was firm enough, a new layer of paint patterns could be placed. Several layers of paint and resin were done to gain the required 3D effect. Several types of special eyes were made for comparison. In the figure (Fig. 6) below, a comparison between eyes with glass-made coloring (left), painted (middle), and paint with resin layers (right) can be seen.

Figure 6 Comparison of eyes made by different techniques

A more detailed comparison of the results from the production of the complex eye by each technique was made.

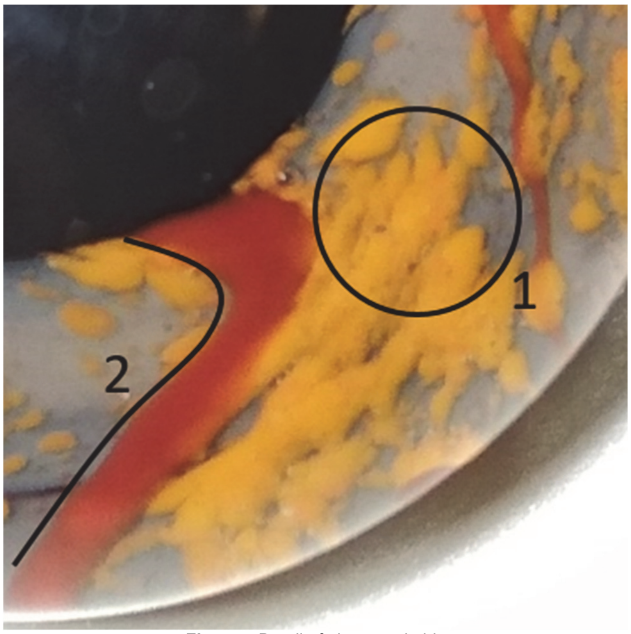

Figure 7 Detail of glass-made iris

In the figure (Fig. 7), the 3D relief is made by glass particles (1). Glass texture creates an organic look of the iris. In the area marked (1), particles sometimes can connect and form a big structure. This may or may not be a harmful effect. The area marked (2) shows the curvature of the linear shapes. During the processing, linear shapes were deformed and twisted - this is a crucial defect on the eye.

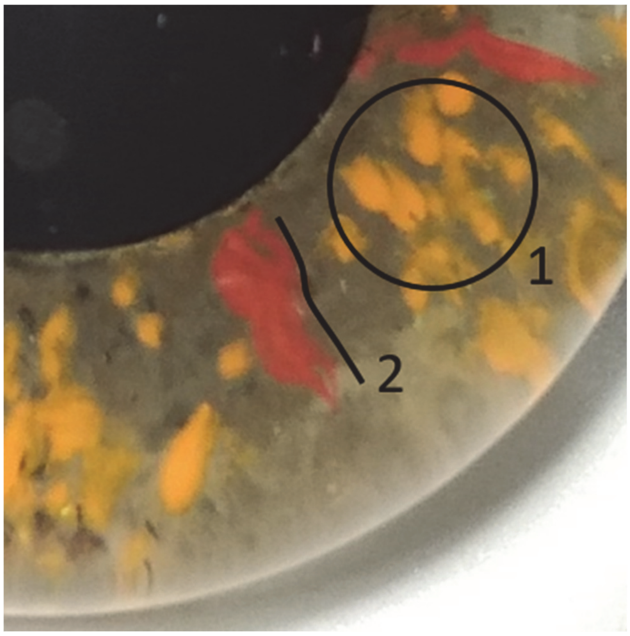

Figure 8 Detail of painted iris

The painted iris in the figure (Fig. 8) can have more detailed shapes with better control of creating the shape or color. In the area marked (1), small orange particles with a good detail rate can be seen. Unfortunately, there is no 3D relief. Straight lines can be painted as demanded (2). Painted iris can have good details but for the cost of no plasticity.

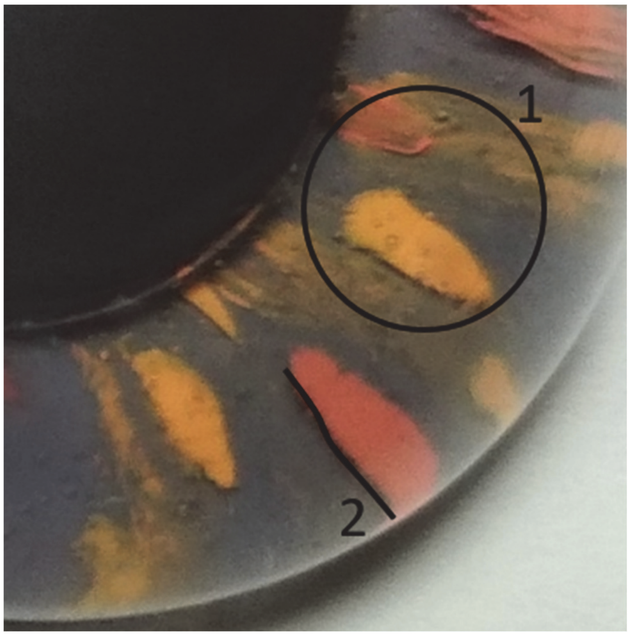

Figure 9 Detail of iris made by layered painting

The proposed technique of layered painting in the figure (Fig. 9) shows that there can be achieved the 3D effect by a layering of the resin and paint. In the area marked (1), the 3D effect can be seen. Linear shapes can also be painted as demanded (2). In this particular case, orange particles seem to be much bigger than previous techniques. That is caused by a lack of experience with the new technique and can be improved in the future.

From the comparison, it is clear that the proposed solution can be used to overcome the problem. The technique should be optimized to achieve excellent results. The possibility of bubbles between resin layers should be considered. Also, the painting technique should be enhanced to get a more realistic look of the iris.

Due to the time when individual layers of resin must dry, this proposed technique should be used only for eyes with a higher degree of demanded details of coloring. Theoretical dependence of production cost to demanded detail is visualized in Graph (Fig. 10) below.

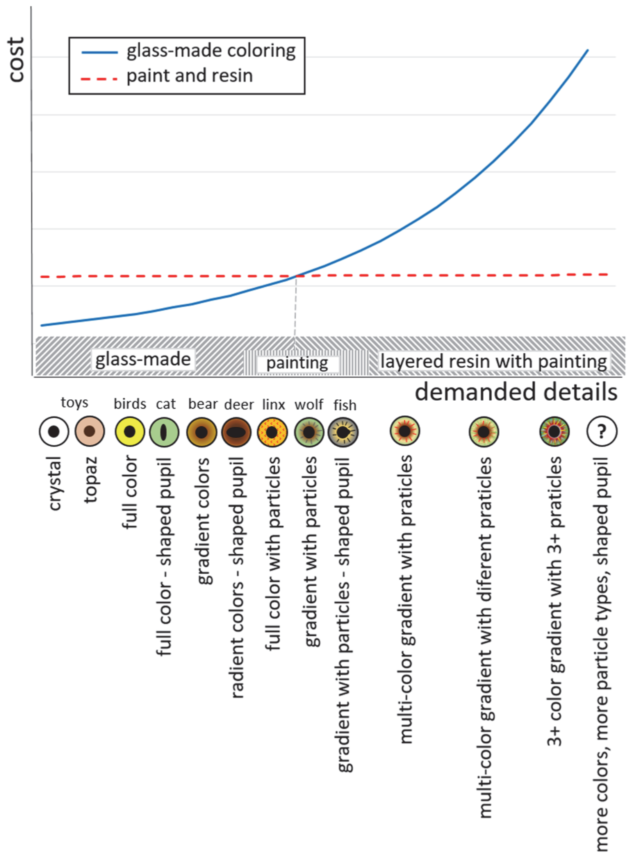

Figure 10 Comparison of costs of production techniques related to demanded details of the eye

Fig. 10 shows a comparison of the cost related to the complexity of the eye detail based on the production technology. For clearance, representative categories of eyes are under the *X* axis, together with the typical type of eye. On the left side, there are easy eyes for toys or with only one- full-colored iris. On the right are highly complex eyes without constant or repetitive demand, used mainly for costumes, statues or movie/theatre props. Eyes with a low degree of demanded details, like eyes with a one-color background, should be created using the original glass-made technique. There are low costs, and even though there is only one color, the iris still has plastic relief. The proposed layering technique should produce eyes with a high degree of demanded details. It helps to reduce costs while sustaining the 3D effect of the iris. Painting can be used for simple colored eyes with a low degree of detail.

The limitation of this proposed technique is the time of resin drying. The use of UV-active resin can solve this. Another problem can be bubbles inside of the resin, which a vacuum box can eliminate. During the painting, details must be painted very small, the glass body of the eye works as a lense, and the painting on the final result seems slightly bigger. This optical effect could be used for the creation of deep relief.

The toxicity or environmental effects of the use of the resin can be discussed. Due to the purpose of product use - taxidermy, statues, costumes, or props for movies or theatre, there is no need to follow any strict safety norms. All used glass should not contain any lead [24]. A protective mask and clothes should be worn during resin processing to prevent health risks. After curing, the resin should be quite safe. Also, the back side of the eye, where the resin layers are, is sealed by other materials and glues used on the final product. As an option, some healt and environmentally more friendly types of resin are recommended [25-27].

As the next step for eye improvement, different approaches could be made. Layers of the resin can be shaped during the drying to achieve an even more realistic texture. Objects can be included inside the resin. That can be printed images of real animal eyes, natural objects such as rocks, or leaves for special unrealistic eyes (for fantasy creatures). Substances as light-sensitive powders can be added to gain extra optical effect. As was mentioned above, the use of UV-active resin could make the process much faster.

4 CONCLUSION

The method for innovation by increasing ideality was successfully applied to the problem with the production of special custom orders of glass eyes. The final proposed solution is to make a crystal clear eye from glass and colored iris by layering paint and resin. This leads to creating the 3D effect of the iris, with relatively easy processing. The solution is overcoming physical and technical contradictions defined by TRIZ. Separation in space and time, and several inventive principles were used. The proposed technique was tested on several types of coloring with satisfying results. There is also the assumption that the coloring technique will be improved with more practice, and results will be even better. Also, several ways of future improvement were proposed.

The proposed technique is not the best technique for any occasion. Production should be divided by the rate of demanded details on the eye. And when there is a need for a low rate of details, original glass-made coloring is better, and it is less expensive. The proposed technique should be used only for unique and very detailed eyes or eyes with hard-to-combine color combinations.

The layering technique can rapidly decrease the time, costs, and defects of the production of unique glass eyes prototypes.

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