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Enhancing Cable Gland Design Efficiency through TRIZ-Driven Innovation

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Abstract: This study introduces a novel approach to cable gland design through the utilization of TRIZ tools. The tools applied include Function Analysis, the Contradiction Matrix, Trimming, and the 40 Inventive Principles. Function Analysis was used to dissect the cable gland's primary functions, while the Contradiction Matrix and Trimming aided in identifying and resolving design contradictions [1-4]. Additionally, the Inventive Principles provided a structured framework for generating innovative solutions to reduce component count and simplify installation. By incorporating these TRIZ tools, this research achieved a significant reduction in components while addressing key challenges in cable gland design.

A cable gland serves two primary functions: retaining and sealing cables within an enclosure, while also offering secondary features such as earthing and cable protection. The number of components in a gland type is determined by functional requirements. Given its classification as a low-cost, high-volume product, the competitive edge lies in achieving reduced selling costs and simplified installation. Addressing key challenges, which include a high component count (currently nine) and a cumbersome installation process, forms the core focus of this work. The research outlines the TRIZ-guided process and methodology employed to devise inventive solutions to these issues, resulting in a component reduction from nine to four. Moreover, the study encompasses the incorporation of various constraints in the development of efficient cable gland designs, yielding several innovative concepts. The paper introduces proposed system designs and architectures, established based on TRIZ-derived inventive principles, paving the way for subsequent system prototype development.

The work underscores the accelerated problem identification and solution generation facilitated by TRIZ tools. This study demonstrates the effectiveness of TRIZ methodologies in accelerating problem-solving and fostering innovative solutions in cable gland design[5-9]. The evolving concept is presently situated within the feasibility and design phase, effectively addressing both primary and secondary challenges through TRIZ methodologies.

Introduction

A cable gland, more often known as a cable connector or fitting, is a device designed to attach and secure the end of an electrical cable to the equipment. Technically, they are mechanical cable entry devices. They are used throughout several industries in conjunction with cable and wiring used in electrical instrumentation and automation systems. Cable glands may be used on all types of electrical power, control, instrumentation, data, and telecommunications cables. They are used as a sealing and termination device to ensure that the characteristics of the enclosure which the cable enters can be maintained adequately. Cable glands are made of various plastics, steel, brass, or aluminum. glands intended to resist dripping water or water pressure will include synthetic rubber or other types of elastomer seals. Certain types of cable glands may also serve to prevent entry of flammable gas into equipment enclosures, for electrical equipment in hazardous areas.

Cable gland primarily serves two main functions, cable retention and cable sealing into an enclosure. It also enables earthing and provides cable guarding. The functional requirements dictate the number of components in a gland type. Being a low cost- high volume product, the competitive advantage lies in lower selling cost serving wider range of cable sizes and Installation ease.

To start with Raychem RPG E1W type cable gland which is generally used for armored cable, also known as armored cable gland, was taken as base model and functional modelling of components were performed in TRIZ and models of solution were proposed.

Functional Modelling

The Function Analysis tool is a systematic way of identifying and understanding the functions of a system. It can be used to improve the design of a system by identifying unnecessary or inefficient functions, and by finding new ways to perform the necessary functions [6].

The armoured cable gland consists of nine components such as the cable passes through the first metallic component known as compression ring. The main functionality of the compression ring is holding the cable and acting as a passage/guide toward the metallic box often known as junction box. The compression ring is provided with compression seal (B) which mainly assures, or the primary function is, ingress protection of the cable as it moves inside. Compression seal (B) though made up of rubber has secondary function of holding the cable. A plastic retainer ring is provided in between compression ring and compression seal (B) to avoid any mechanical damage to the latter.

Body armour, being the main component of assembly performs several functions, primarily being holding body armor lock and cable entering inside. Body armor is the junction where the armor of the cable gets separated for the purpose of earthling performed using two components name as cone ring and cone. Body armor house the cone ring and cone and make sure that segregation of armor from the cable happen just after the cone ring. Armor gets attached over the tapered zone of the cone while the core cable passes through it. The cone ring further assures that armor is tightly attached over the cone. Later, for additional protection compression seal (S) is provided as secondary component for ingress protection. Body armor lock is provided to house the compression seal (S) primarily and to help the system attached to the metallic box (junction box) using lock nut. The lock nut goes inside the junction box (metallic box) and holds the cable gland system tightly by holding the lock nut through mechanical threads. The complete details of the components are shown in figure 1.

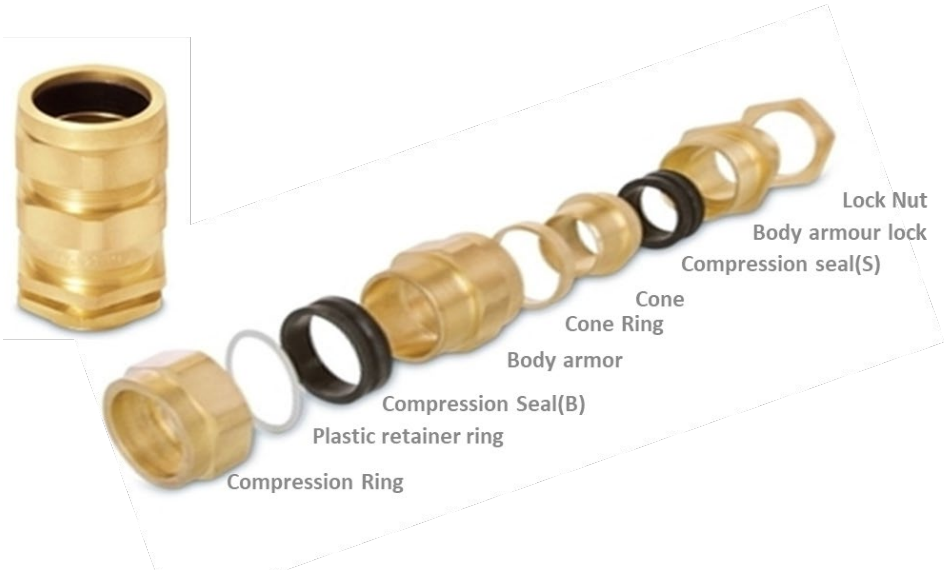

Figure 1 E1W cable gland engineering system and its components

To build up a Function Analysis, Component Analysis was performed over the components and interactive system by segregating them. Table 1 shows the elements of cable gland system segregated into components and super components. Super system components could be objects (not in the meaning of the object of a sentence but as a physical object), fields, systems and resources that are 'close' to the engineering system that should be modeled. Junction box, cable, human and oil/ moisture/ air are those elements in the system that cannot be influenced and therefore marked as super system. The other components of the engineering system as mentioned in Figure 1 are levelled as components.

Table 1 Elements of a functional model

Component	Super component
Lock Nut	Junction box/ Mounting Platform
Body armour lock	Cable
Compression seal(S)	Human
Body armour	Moisture/Oil/Flame
Cone	
Cone Ring	
Compression Ring	
Compression Seal(B)	
Plastic retainer ring	

Function models highlighting the functions, their usefulness and performance level are shown in figure 2. For instance, lock nut is a function carrier which restricts the movement of body armour lock is a normal function ranked as auxiliary function (Au). Similarly, an insufficient function is performed by lock nut over the junction box where it holds/pushes it changing the surface area as property. Therefore, it is ranked as an additional function (Ad). A basic function(B), though insufficient, is performed by body armorer lock over the cable by housing it.

It is to be noted that the main function of the engineering system is to hold the cable. The target of the engineering system is cable, hence basic rank is assigned to cable. Basic function(B) is a useful directed toward a target(cable) of the current analyzed engineering system. An additional function (Ad) ac on a component of the supersystem except the target(cable) and an auxiliary function (Au) act on a component of the analyzed engineering system.

Further, if the function has performed exactly as the way, it is designed is designated as normal function as shown in Figure 2. An excessive or insufficient performance is considered as in issue.

Function Carries	Function Receipient	Function	Rank	Performance Level
Lock Nut	Body Armour lock	Restricts the Movement	Au	Normal Function
	Juntion box	Holds/Pushes	Ad	Insuffient Function
Body Armour lock	Lock Nut	Restricts the Movement	Au	Normal Function
	Compression seal(S)	1.Hold 2.Encapsulation	Au	Normal Function
	Cone	Restricts the Movement	Ad	Normal Function
	Body armour	Restricts the Movement	Au	Normal Function
	Cable	Houses	B	Insuffient Function
	Juntion box	Sealing	Ad	Insuffient Function
	Earth Tag	Holds/Pushes		Excessive Function
	Shrouds	Sticks		Excessive Function

Figure 2 Function ranking of lock no and body armour lock

In this way functional ranking was performed, functional levels were identified as normal, insufficient, excessive, and harmful and functional body diagram was developed as shown in figure 3. It is therefore in the context of the E1W cable gland, the Function Analysis tool is used to identify the following functions:

To hold the cable and protect it from moisture, oil, and flame.
To provide a passage for the cable into the junction box.
To prevent the cable from being pulled out of the gland.
To provide earthing for the cable.

The Function Analysis tool can also be used to find the performance level of each function[7]. For example, the function of holding the cable is performed adequately by the compression ring and compression seal. However, the function of providing grounding is not performed adequately by the cone and cone ring. This is because the cone and cone ring are not able to provide a secure connection between the cable armour and the junction box.

The Function Analysis tool can be used to find potential improvements to the E1W cable gland. For example, one potential improvement would be to redesign the cone and cone ring to provide a more secure connection between the cable armour and the junction box. Another potential improvement would be to add a second compression seal to provide additional protection against moisture and oil.

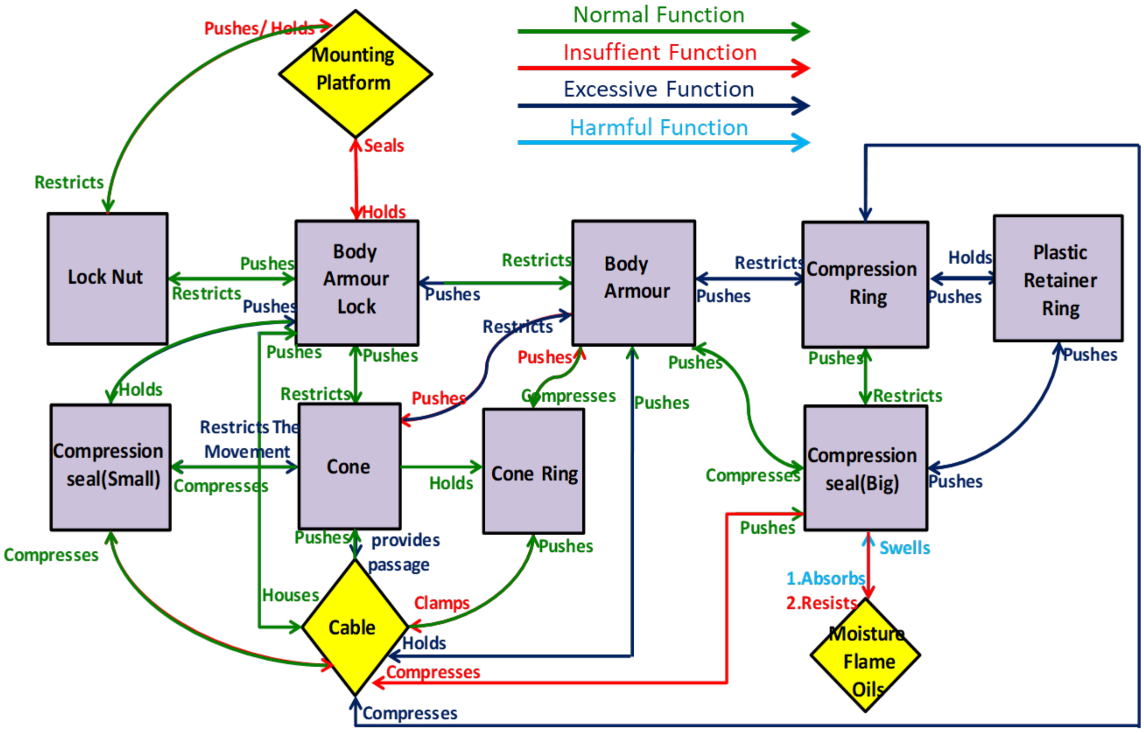

Figure 3 Functional body diagram of cable gland

The Function Analysis tool is a powerful tool that can be used to improve the design of a system. By identifying and understanding the functions of a system, and by identifying potential improvements, the Function Analysis tool can help to create a more efficient and effective system.
CECA - Cause and effect chain analysis

Many disadvantages are identified during functional analysis, which are caused by a few underlying key disadvantages. Functional analysis exposes the functional shortcomings of the engineering system, as revealed through the functional body diagram. Conversely, CECA systematically organize these drawbacks, particularly those arising from an excessive number of components that contribute to system complexity, and it also uncovers previously concealed issues, occasionally extending beyond the system's defined boundaries[8,9]. CECA is used to identify the key disadvantage of the engineering system, accomplished by building cause - effect chain of disadvantages that link the target disadvantage to its fundamental causes. It was done to understand the inter-dependence of its disadvantages of the system.

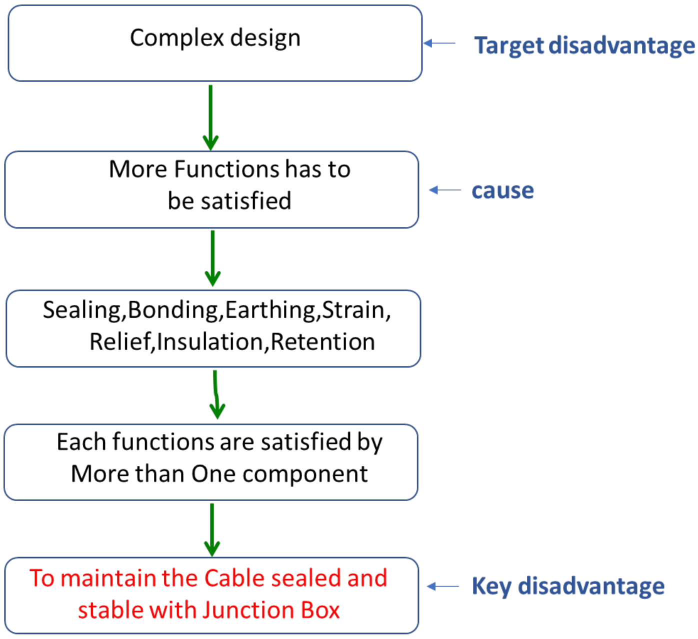

Figure 4 Cause effect chain analysis of the engineering system

With the understanding of CECA, it was identified that root cause of the engineering system was a greater number of components. For instance, two functions are satisfied by 5 components i.e., holding is done by compression ring 1, grip ring, body armor lock components and sealing is done by compression ring 2, mechanical seal, body armor lock and so on. Table 2 highlights the function of engineering subsystems being performed by various components. For example, retention of the cable inside the metallic box (junction box) is performed by lock nut however other components such as cable, junction box and body armor lock can also perform the same function as evident from functional body diagram in figure 3. Components highlighted in red are the super system.

Table 2 Functions performed by various components.

Sealing	Bonding	Earthing(or) Ground	Strain Relief	Insulation	Retention
Compression Seal(BIG)	Cone ring	Earth Tag	Body armour Lock	Shoruds	Lock Nut
Compression Ring	cable	Junction Box	Body Armour	Compression seal(BIG)	Cable
Cable	Junction Box	Body Armour Lock	Compression ring	Compression seal(SMALL)	Body armour Lock
Plasastic retainer ring	Body armour Lock		Cable		Junction Box
Compression seal(SMALL)	Cone				
Moisture					
Cone					
Body armour					

Trimming

TRIZ helps to trim away unnecessary components by thinking about how some components of the system may deliver the functions that currently other components deliver. A trimmed system not only costs less, but it also has less scope for uninvited harmful functions to appear and is thus doubly desirable. Components of the engineering system were trimmed, in various steps, when it was observed carefully about how to deliver the functions we want.

Step 1 - Trimming the compression seal (small) and compression seal (big)

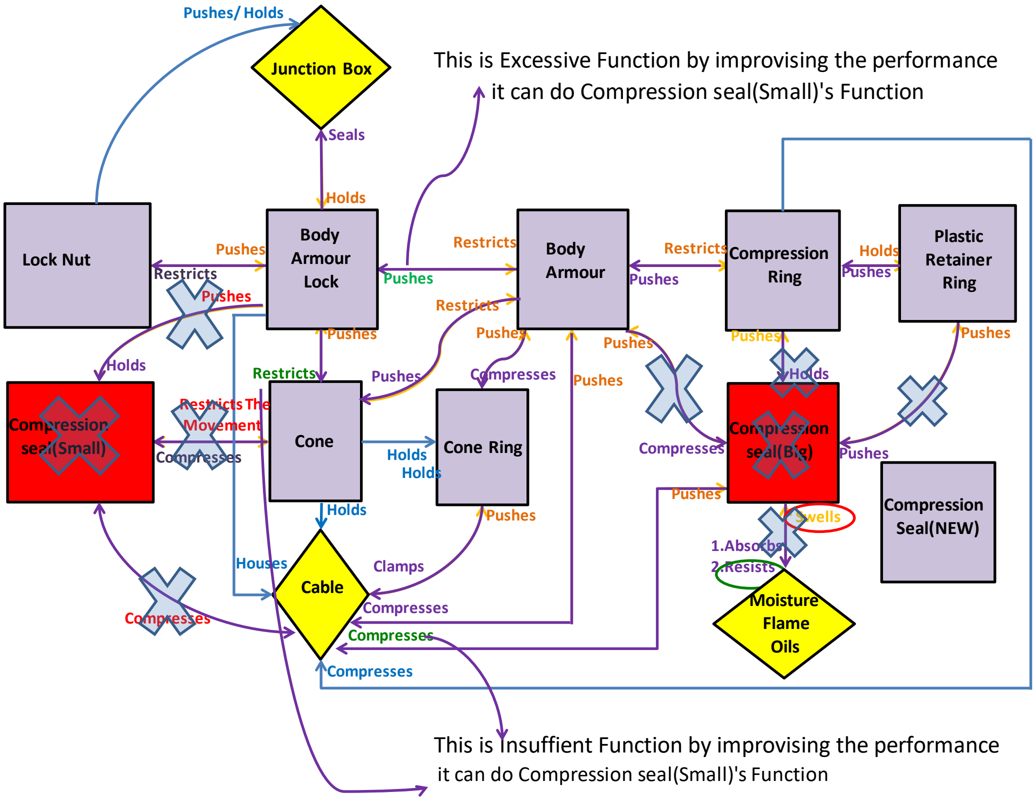

Figure 5 FBD for eliminations of compression seals

Compression seal (small) and compression seal (big) are functions carriers which perform functions such as compressing the cable, pushing the body amour lock, body armor, compression ring, restricting the cone movement and resisting the moisture flame oil as shown in figure 5. trimming rule 3 was applied i.e., functions of compression seals can be performed by one new component in the following ways:

- Compressing the cable done by compression seal new.
- Restricting the cone movement can be done by body armor lock.
- Pushing the body armor lock can be done body armour.
- Resisting the moisture/flame/oil can be done by new compression seal.
- Hence, a new component was introduced as compression seal (new) will replacement of both compression seals. The functional body diagram is shown in figure 6.

Step 2 - Trimming the cone.

Cone as a function carrier of the engineering system performs function of pushing body armor lock, restricts the movement of body armor, provides passage for cable, and holds the cone ring. trimming rule 2 was applied i.e., functions of cone seal can be performed by other components in following ways:

- Pushing body armour lock can be done by body armour.
- Restricting the movement of body armour can be done by body armour lock.
- Providing passage for cable can be done by body armour lock.
- Holding the cone ring can be done by body armour.
- Hence the cone was trimmed, and functionality was assigned to body armor lock and body armor as shown in figure 7.

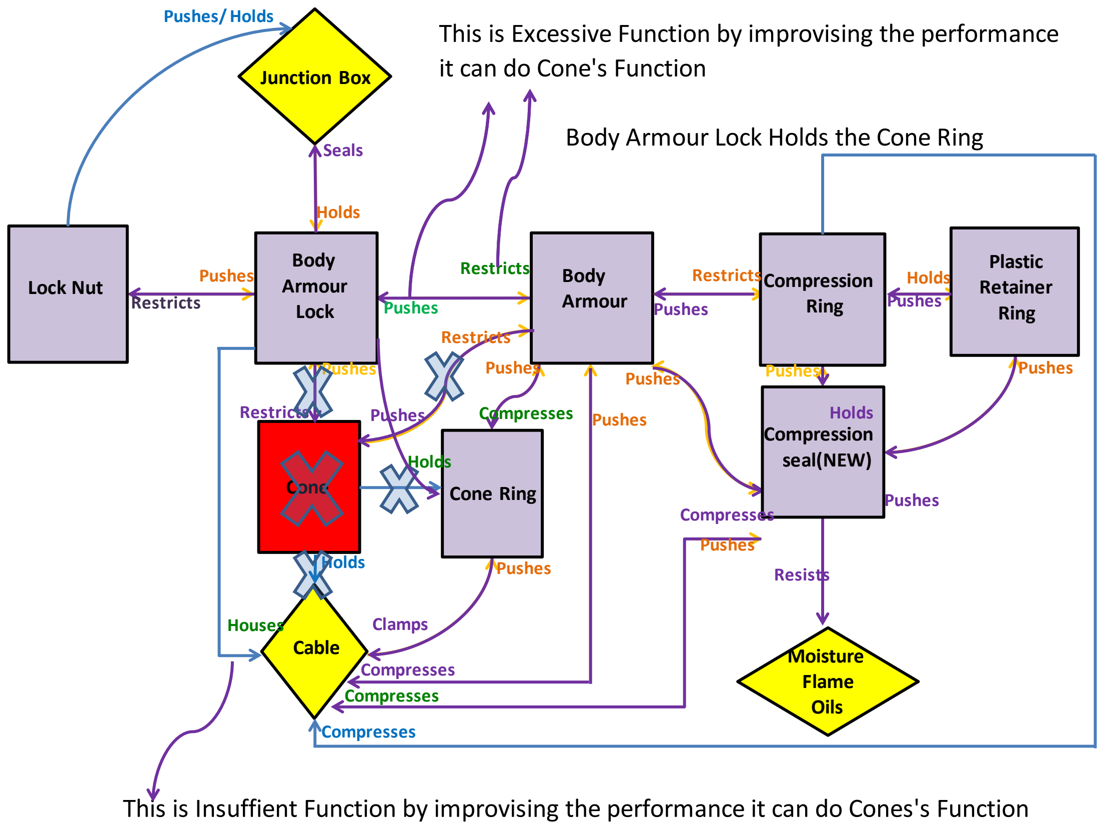

Figure 6 FBD for elimination of cone ring

Step 3 - Trimming the body armor.

Body armour as function carrier of the engineering system perform function of pushing body armour lock, restricts the movement of compression ring, compresses the cone ring, compresses the compression seal (big) and compresses the cable as shown in figure 7. Under the pretext of trimming rule 2, functions of body armour can be performed by other components in the following ways:

- Push in body armour can be achieved by compression ring.
- Restriction in the movement of compression ring can be achieved by body armour lock.
- Compressing the cone ring can be done by compression ring.
- Compression of the compression seal (big) can be achieved by body armour lock.
- Compression of the cable can be achieved by body armour lock.

Hence the body armour was trimmed, and functionality was assigned to body armor lock and compression ring as shown in figure 8.

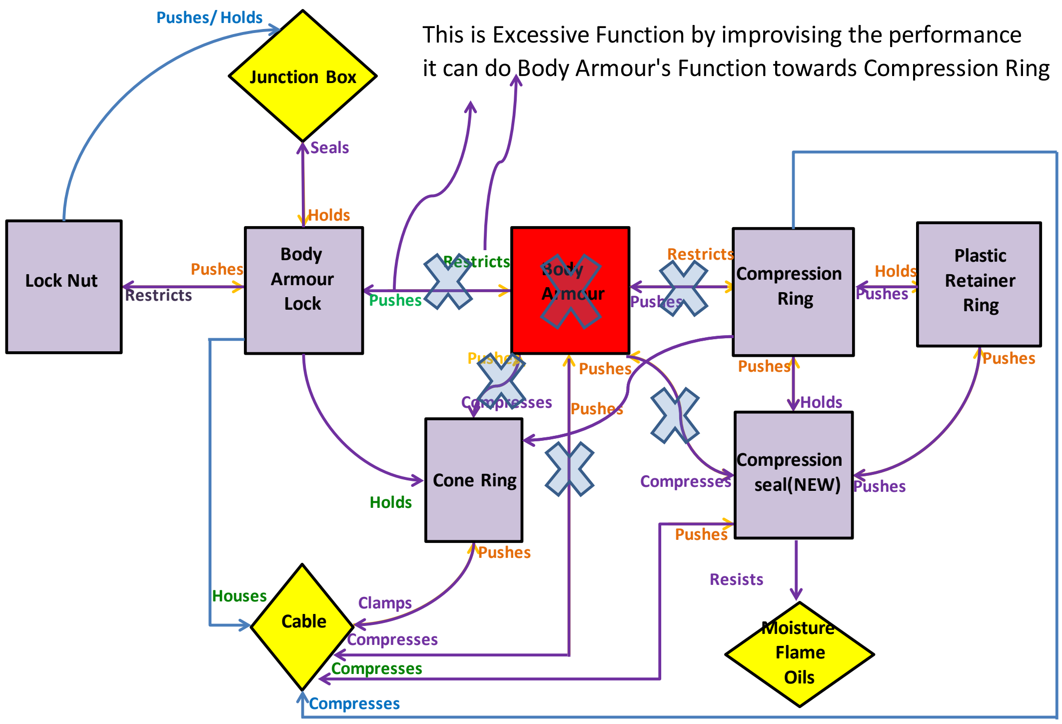

Figure 7FBD for elimination of body armour

Step 4 - Trimming the plastic retainer ring.

The plastic retainer ring as a function carrier of the engineering system performs the function of pushing compression ring and compression Seal (big) as shown in figure 8. Under the pretext of trimming rule 2, functions of plastic retainer can be performed by other components in the following ways:

- Pushing compression ring is an excessive function, can be performed compression ring itself.
- Pushing compression seal (big) can be performed by compression ring.

It is therefore plastic retainer ring was trimmed and functionality was assigned to compression ring and compression seal as shown in figure 9.

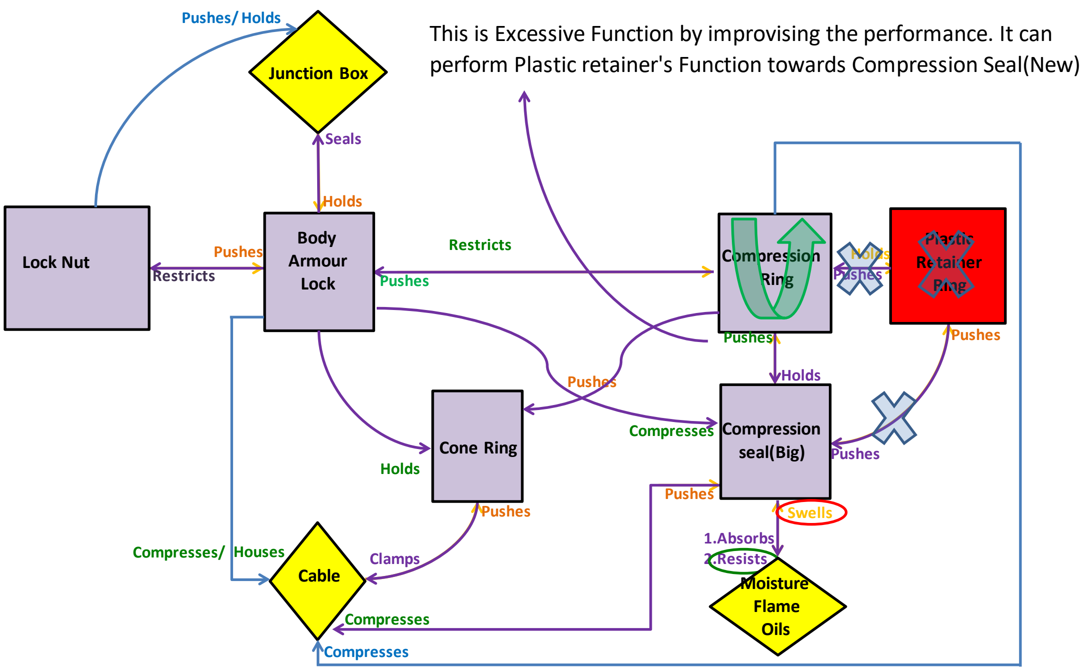

Figure 8 FBD for elimination of plastic retainer ring

Step 5 - Trimming the cone ring.

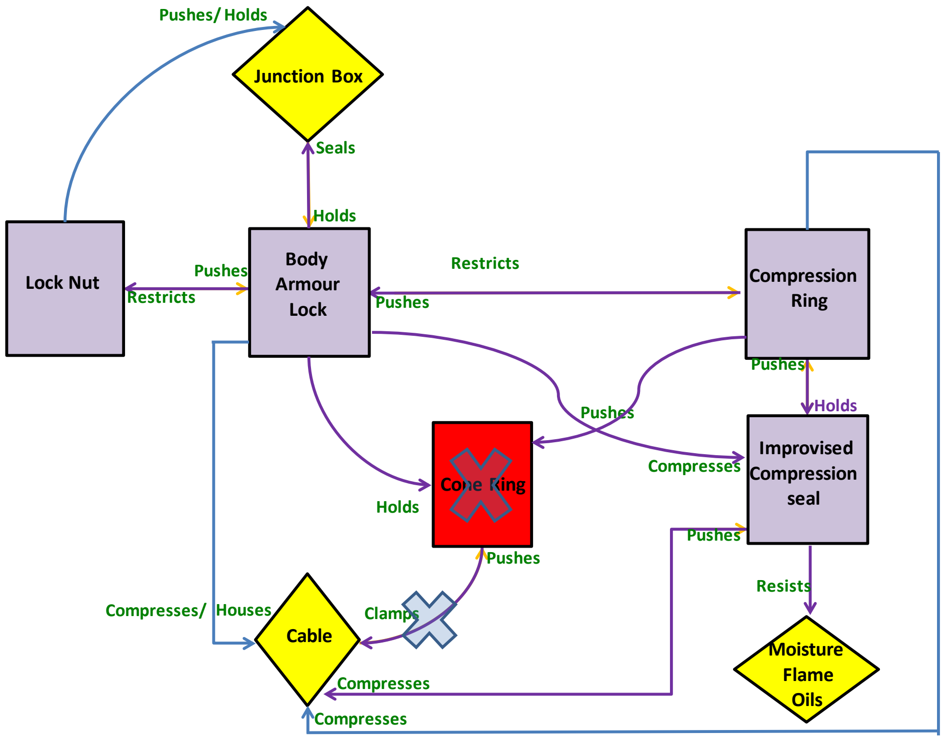

Figure 9 FBD for elimination of cone ring

The only function of the cone ring as a function carrier was to clamp the cable with armour. With trimming rule 2, cone ring was trimmed, and the functionality was assigned to body armour lock.

Final trimmed model

In the final trimmed model of the engineering system, as shown in figure 10, we had new compression ring and new (improvised) compression seal introduced with additional functionality of body armour and plastic retainer ring and new body armour lock introduced with functionality of cone, cone ring and body armour lock removed during the trimming process.

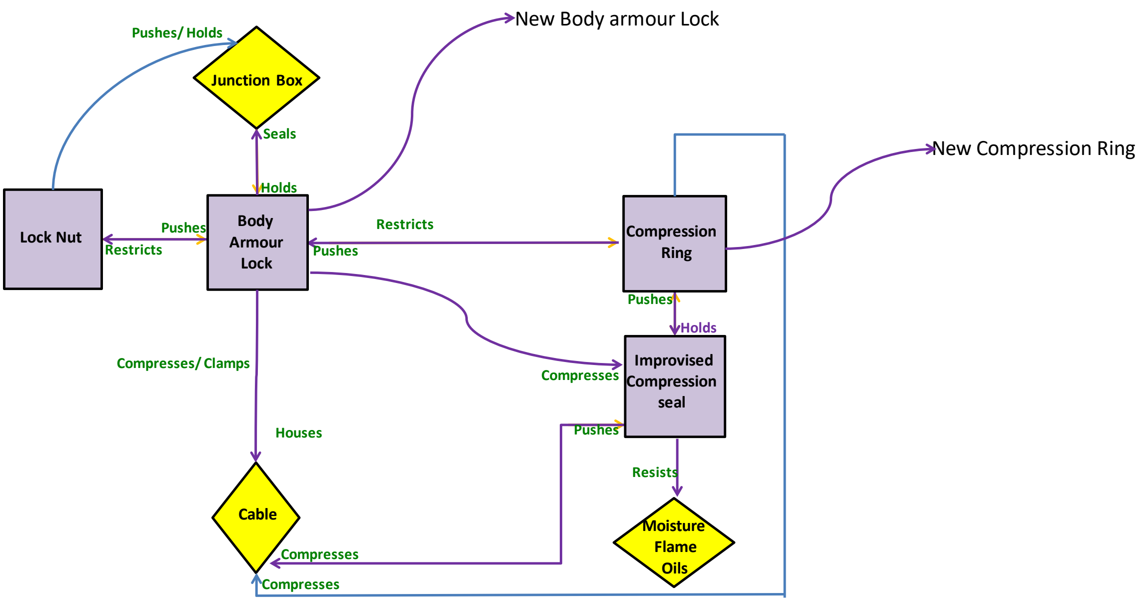

Figure 10 Final trimmed model of engineering system

Contradictions and Evolution of Concepts

According to TRIZ, often the most effective inventive solution to a problem is the one that overcomes some contradictions. A contradiction shows where (in so-called operative zone) and when (in so-called operative time) a conflict happens. Contradiction, in TRIZ, happens when solving one improving parameter or characteristic of a technique negatively affects the same or other characteristics or parameter of the characteristics. An action is simultaneously useful and harmful; the introduction or amplification of useful function or the recession of the harmful effects lead to deterioration of some subsystems or the whole systems [1]. For example, in the current case, retention of cable is the improving parameter which is achieved only when cable is held as shown in figure 11. However, to hold the cable an additional support system is required which will increase the overall cost of the system in terms of components. Hence, the contradiction obtained was maintaining cable retention with no additional support required. Improving and worsening parameters for the contradiction were identified from 40 engineering parameters as mentioned in table 3.

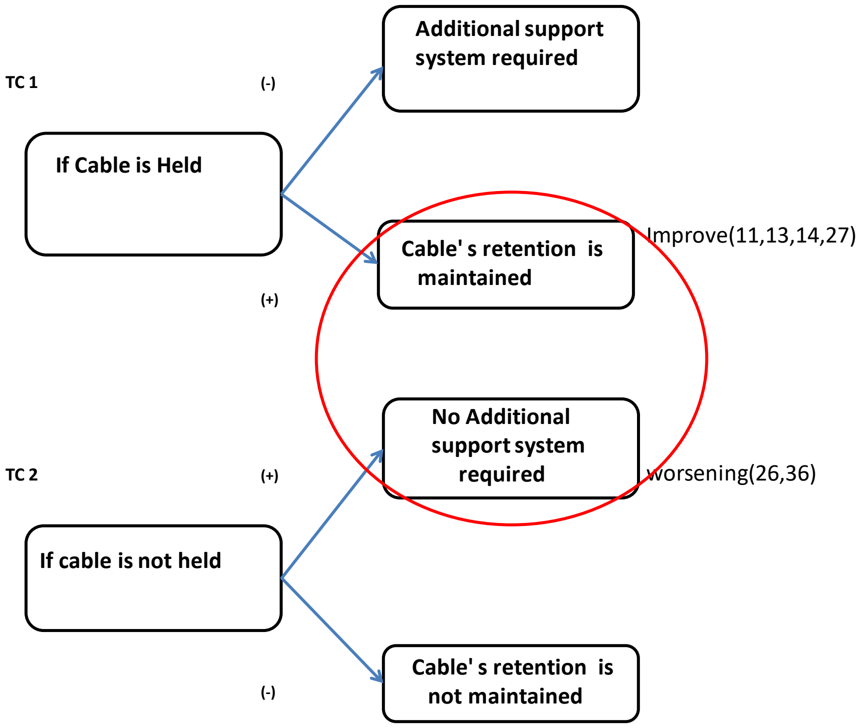

Figure 11 Contradictions for holding and sealing cable with junction box.

Table 3 Improving and worsening parameter from 40 engineering parameters

Improving Parameters	**Worsening Parameters**
11 - Tension or Pressure	26 - Amount of Substance
13 - Stability of Object	36 - Complexity of Device
14 - Strength	
27 - Reliability	

Altshuller matrix was formed between improving and worsening factors to identify the underlying inventive principles as shown in figure 12. Based on the principles obtained, ideas were generated to give a shape to final concept as shown in table 4.

Improving Factors		11	13	14	27
Worsening Factors	26	10,19,38,29	36,10,14	36,22	35,38,18,16
	36	10,4,28,34	19,1,35	16,29,1,28	6,29

Figure 12 Altshuller Matrix for identifying underlying principles.

In a similar event, Ingress protection of cable (by preventing air, water, and dust seepage) is the improving parameter which is achieved only when cable is sealed as shown in figure 13. However, to seal the cable an additional support system is required which will increase the overall cost of the system in terms of components. Hence, the contradiction obtained was sealing cable with no additional support required. Improving and worsening parameters for the contradiction were identified from 40 engineering parameters as mentioned in the table 5.

Table 4 Idea generated against inventive principles.

No	Principle	Idea Generated
1	Segmentation	Segmenting the body armour lock to provide grip
4	Asymmetry	making plastic part with asymmetric diameter to compress the cable
6	Universality	Eliminating Part-Transferring function to others
14	Spheroid	Attach one String at the end of body armour lock and compression ring
22	Convert a Harm into Benefit	Water observing mechanical seal instead of resisting-will expand with presence of water
35	Transformation of physical and chemical action	Using chemical bonding instead of physical

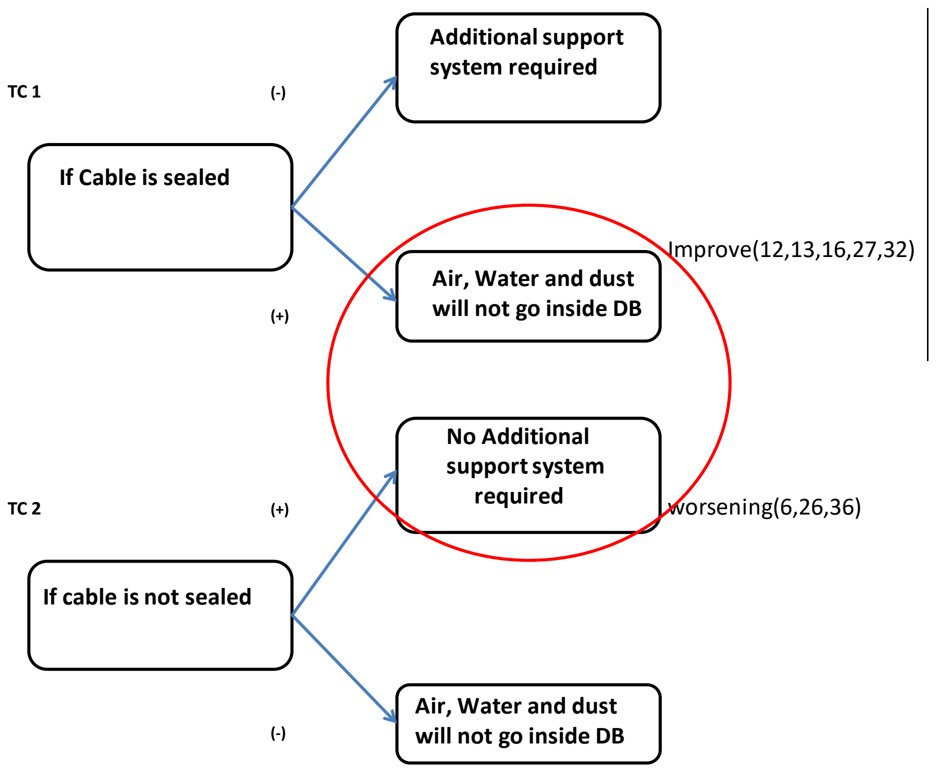

Figure 13 Contradiction of cable sealing with junction box

The E1W cable gland encounters key contradictions which're as follows.

• One contradiction is the requirement to securely hold the cable without requiring support. The existing design of the cable gland utilizes components such, as the compression ring, compression seal and body armour lock to achieve this. However, these components increase the weight and complexity of the design. This can potentially lead to failures.

• Another contradiction is the need to effectively seal the cable against moisture, oil and flames without relying on support. The current E1W cable gland design incorporates components like the compression seal, cone ring and cone, for this purpose. Nevertheless, these components add complexity and weight to the design while also increasing the risk of failures.

Table 5 Improving and worsening parameter from 40 engineering parameters as taken from Altshuller Matrix

Improving Parameters	**Worsening Parameters**
12 - Shape 13 - Stability of Object 14 - Strength 27 - Reliability 32 - Ease of manufacture	06 – Area of stationary object 26 - Amount of Substance 36 - Complexity of Device

Improving Factors → / Worsening ↓		12	13	16	27	32
	6	-	2,38	2,10,19,30	32,35,40,4	40,16
	26	35,14	15,2,17,40	3,35,31	18,3,28,49	29,1,35,27
	36	29,13,25,15	2,22,17,19	-	13,35,1	26,27,1,13

Figure 14 Altshuller Matrix for identifying underlying principles.

Altshuller matrix was formed between improving and worsening factor to identify the underlying inventive principles as shown in figure 14. Based on the principles obtained, ideas were generated as workable solutions to give a shape to final concept as shown in table 6.

- Use of composite materials. Composite materials can be used to create seals and other components that are both strong and lightweight. This can help to reduce the weight and complexity of the E1W cable gland, while still providing the necessary functions.
- Asymmetry. Asymmetric designs can be used to create components that can perform multiple functions. For example, an asymmetric body armour lock could be used to both retain the cable and provide a ground connection.
- Transformation of physical and chemical action. Chemical bonding can be used to create seals that are stronger and more durable than traditional seals. This can help to reduce the risk of failure.
- Conversion of harmful effects into useful ones. The water absorption of some materials can be used to create seals that expand when they come into contact with water. This can help to create a more effective seal.

Table 6 Idea generated against inventive principles.

No	Principle	Idea Generated
4	Asymmetry	making rubber part with asymmetric diameter to compress the cable
31	Use of porous materials	Make small holes in mechanical seal
35	Transformation of physical and chemical action	use chemical adhesive
40	Composite materials	Use composite mechanical seal (Steal cord)

Based on the ideas generated with reference to the inventive principle, four ideas were conceptualized and alaysed as mentioned as cases :

1. With inventive principle 40, using composite material can be an alternate to provide both sealing as well as holding functionalities. A mechanical seal was designed made up of a composite material i.e rubber for sealing and steel cord for mechannical grip that can provide the grip. The schematic of the conceptual form is shown in figure 15. The overall number of components of the engineering system were reduced to four.

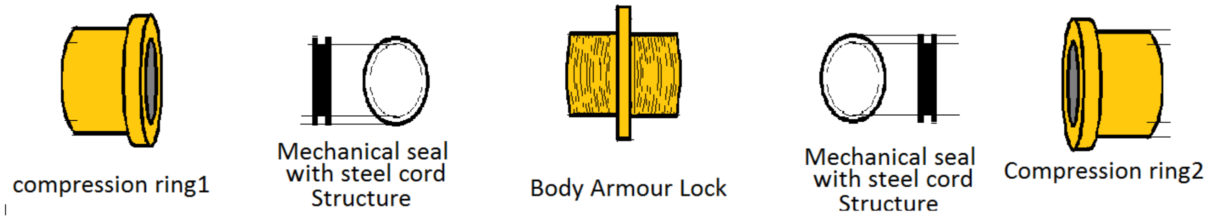

Figure 15 Use of principle: Composite material

2. With the combination of principle of composite materials and asymmetry – a new idea was conceptualised wherein the engineering system had final their components that could perform all the desired functionality. Asymmetry principle made body armour lock asymmetrical in a way such that we can put desired pressure over the cable to hold it tightly and can also be used for tagging the armour for earthing. Sealing cap is provided with a composite material as discussed in case 1 which can perform the functionality of ingress protections (sealing) and holding as shown in figure 16.

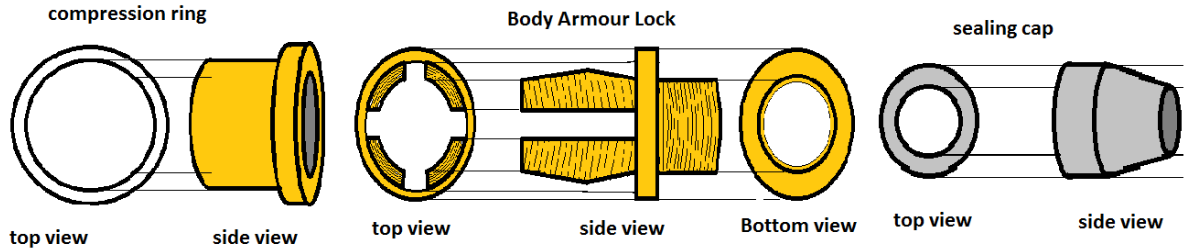

Figure 16 Use of principle: Composite material & asymmetry

3. The help of principle applying composite material and converting a harm into benefit has helped to improve the characteristic of the seal. Seal absorbs water and gets expanded uniformly therefore creating a harmful functionality. It is for the case, chemistry of polyacrylamide material was modified, and composite material was produced and used to make a seal which can absorb water. The schematic of the concept is shown in figure 17.

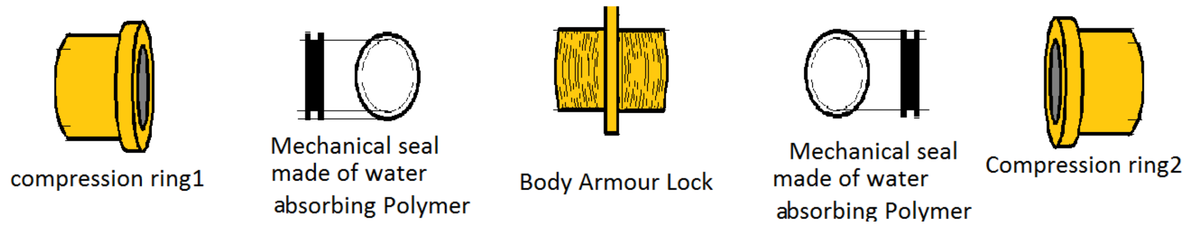

Figure 17 Use of principle: Composite material & converting harmful benefits into useful one.

Acknowledgement

We thank our colleagues from TRIZ association of Asia Multiphysics who provided insight and expertise that greatly assisted the research. Patent has been filed for above discussed [4] and analyzed designs of cable glands.

Conclusion

The paper presented a structured approach to cable gland design that uses a comprehensive set of TRIZ tools. The tools were applied systematically to identify the cable gland's primary functions, resolve design contradictions, and develop innovative solutions [2,3,4].
In current work, the research focused on addressing two critical challenges in cable gland design: the high number of components and the complex installation process. Using TRIZ, the number of components was reduced from nine to four, resulting in a more efficient and cost-effective solution. The versatility of TRIZ methodologies in incorporating various constraints to develop efficient cable gland designs was also demonstrated. The proposed system designs and architectures, which are

based on TRIZ-inspired inventive principles, have help to secure patent for the unique design and laid down the foundation for development of cable gland variants [10].

This work is significant because it accelerates the process of problem identification and solution generation. It also highlights the effectiveness of TRIZ tools in fostering innovative solutions for cable gland design. As the research continues, TRIZ methodologies will be used to address both primary and secondary challenges in other electrical products.

In conclusion, this research not only provides valuable insights into cable gland design, but it also demonstrates the powerful role of TRIZ in enhancing problem-solving and driving innovation in engineering and design disciplines.

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