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TRIZ IMPROVEMENT OF ROTARY COMPRESSOR DESIGN

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ABSTRACT

A rotary compressor with variable capacity is used in air conditioners. An air conditioner is a key product of mass production of Digital Appliance Business of Samsung Electronics Company. Therefore the improvement of design and reliability of air conditioners leads to expansion of the sale and helps the company to preserve leadership position in the worldwide market. In this article the real industrial problem related to removing harmful interaction between compressor components “shaft-pin-double cam-roller-cylinder” and destruction problem of driving pin and cam bush were solved with ARIZ application. It is considered to use into the applied algorithm some new approaches and statements for reforming initial customer’s problem in the line of the future solutions. The development of different new designs of the compressor and its latching mechanism with the aid of applied ARIZ has been analyzed. The outcome of this work obtained with using applied logical algorithm tools are 21 concept solutions combined in 9 international and national patents and application of some of them in mass production of the company with annual income about $10 Million. This article could be useful for TRIZ users like real case study with measured results and how ARIZ was used to develop the solutions.

1. INTRODUCTION

The article mainly presents Algorithm of Inventive Problem Solving (ARIZ) [1] application for the development of the new air conditioner compressor designs and specifically its latching mechanism, which is preventing the bumping phenomena between the driving pin and the double cam-bush. Figure 1 shows the applied ARIZ procedure in that project briefly.

The main goal of the first part of ARIZ is the transition from an indefinite inventive situation to the clearly created and extremely simple model of the problem. The solving area for the future compressor designs was reduced rapidly having cone shape with Ideal Final Result on the top. Then the next part of ARIZ helps to resolve conflicts between parameters of a product guiding to a complete set of breakthrough solutions. These solutions should be placed from Ideal Result as close as possible. During practical implementation of this project and for the development of new design concepts basic ARIZ tools have been used together with new statements.

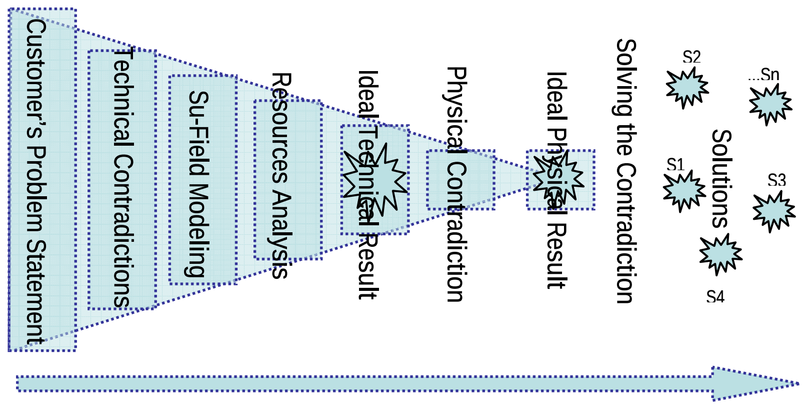

Figure 1. Applied Algorithm of Inventive Problem Solving

These tools indicated in figure 1 and particularly, Technical Contradictions, Su-Field Modeling, Resources Analysis, Physical Contradictions, Ideal Final Result and solving procedures of the contradictions have been applied. Problem solving was carried out in the consecution from left to right shown on the picture and was started from customer's problem statement.

2. CUSTOMER'S PROBLEM STATEMENT

2.1. The Compressor's Features

In order to reduce the indirect global warming contribution, efforts to improve the efficiency of refrigeration systems are being continued. Recently, a variable capacity compressor has been increasingly used in refrigeration systems, such as air conditioners or refrigerators, to vary cooling capacity as desired, thus accomplishing an optimum cooling operation and saving energy. The capacity modulation is a key technology component in the improvement of efficiency. The variable capacity compressor can provide the solution for the capacity modulation. Samsung developed a novel rotary compressor [2], which provides two-step capacity modulation mechanically without using any electronic frequency modulation. It is called "ES compressor" naming after its Energy Saving characteristics. Its major difference from the typical variable capacity compressors that have two cylinders is the variable displacements alternatively operate at each stage according to the external loading condition. ES compressor modulates the capacity in two steps by alternatively operating two cylinders in different compressing volume by a unique latching mechanism of the shaft.

Due to its structural characteristics having an idle cylinder and controlling the eccentricity by rotation direction of shaft, several problems against the stability of the system may occur.

2.2. The Compressor's Structure and Principle

ES compressors are composed of two cylinders like a twin rotary compressor, as illustrated in Figure 2. The variable capacity rotary compressor is operated such that a compression operation is executed in one of the compression chambers having different capacities by the eccentric unit while the idle rotation is executed in a remaining one of the compression chambers, according to a rotation direction of the rotating shaft, thus varying compression capacity of the compressor as desired by simply changing the rotating direction of the shaft.

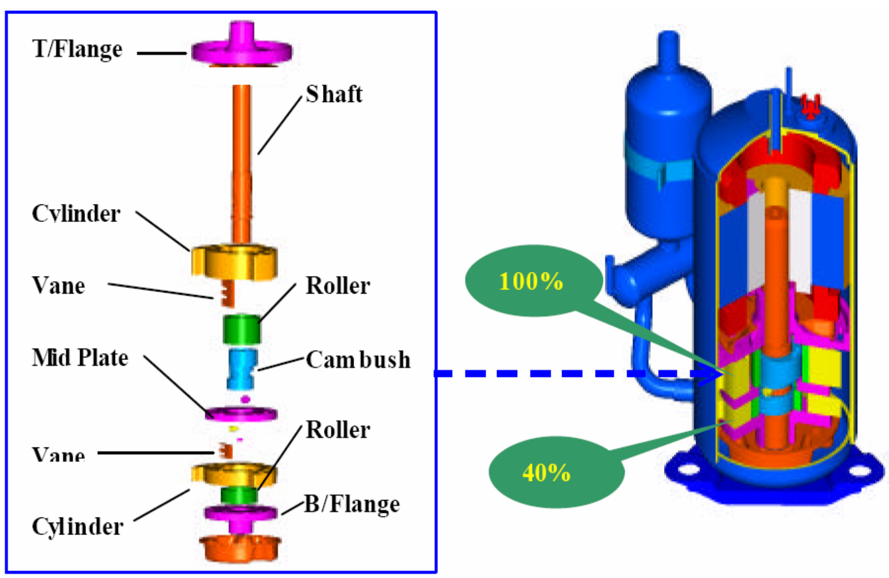

Figure 2. Structure of the compressor

Two cylinders having a different compressing volume are operating alternatively in opposite directions. By changing the rotational direction of a shaft, the eccentricity is controlled and the operating mode of each cylinder is determined.

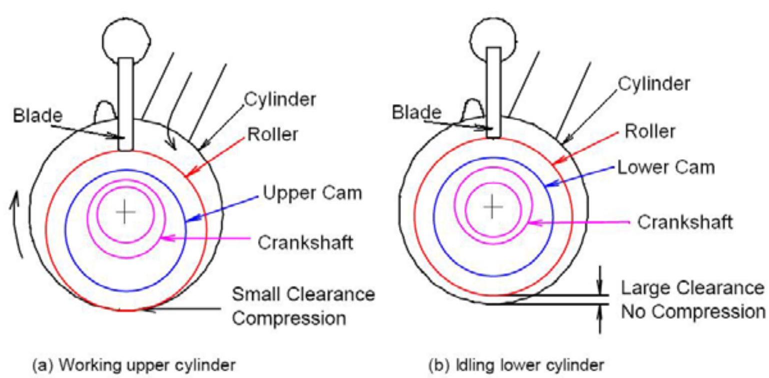

Figure 3. Control of the clearance by eccentricity change

If a shaft rotates clockwise, an upper cylinder compresses the refrigerant while a lower cylinder idles as shown in figure 3. If a shaft rotates in counterclockwise direction, only the lower cylinder works.

ES compressor modulates the capacity in two steps by alternatively operating two cylinders with different compressing volume according to the external load condition as described previously. The eccentricity of a top and a bottom pump are inverted easily according to a motor rotational direction change. The shaft assembly of ES compressor is composed of a shaft, a driving pin, and a cam-bush. The shaft and the cam-bush are designed in order that each pump has its own eccentricity.

The Figure 3 shows the example that the clearance and eccentricity quantity are controlled by rotation direction change of the shaft. When the shaft rotates with clockwise direction, the upper eccentric part of the shaft assembly shows the maximum eccentricity and smallest clearance, while the lower part has a smallest eccentricity and large clearance quantity. In consequence, for the upper pump, the compression function is carried out, but the lower pump idles. On the contrary when the shaft rotates with count clockwise direction, the lower pump does a compression work and the upper pump idles.

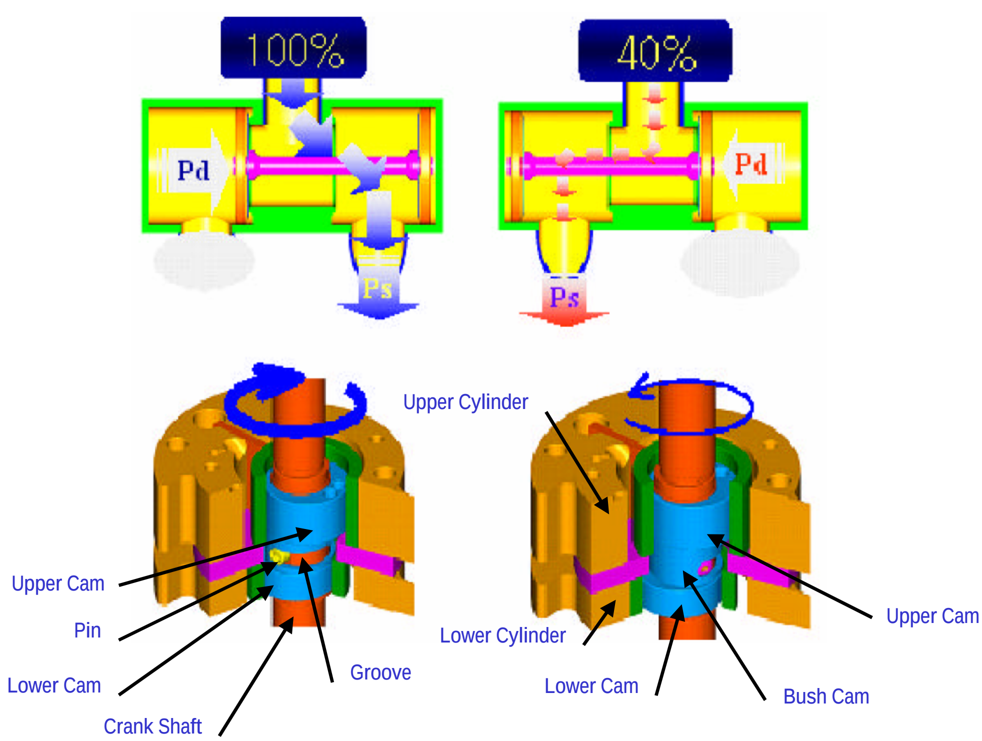

Figure 4. Latching Mechanism and 3-way Valve Operations

A 3-way valve is used to supply the refrigerant of the low pressure to the working cylinder. The 3-way valve automatically switches the path of the suction gas according to the rotational direction of the shaft as shown in figure 4. If a shaft rotates in the clockwise direction, the path of suction gas is opened to the upper cylinder. On the other hand, if a shaft rotates counterclockwise, the path of the suction path is switched to the lower cylinder.

The rotational motion of a shaft is transmitted to a cam-bush by a driving pin. In order to ES compressor working properly, the shaft and the cam-bush must adhere tightly each other while the motor rotates. If the cam bush has a relative speed with the shaft, the bumping noise is generated by the impact and the reliability can get worse. The relative

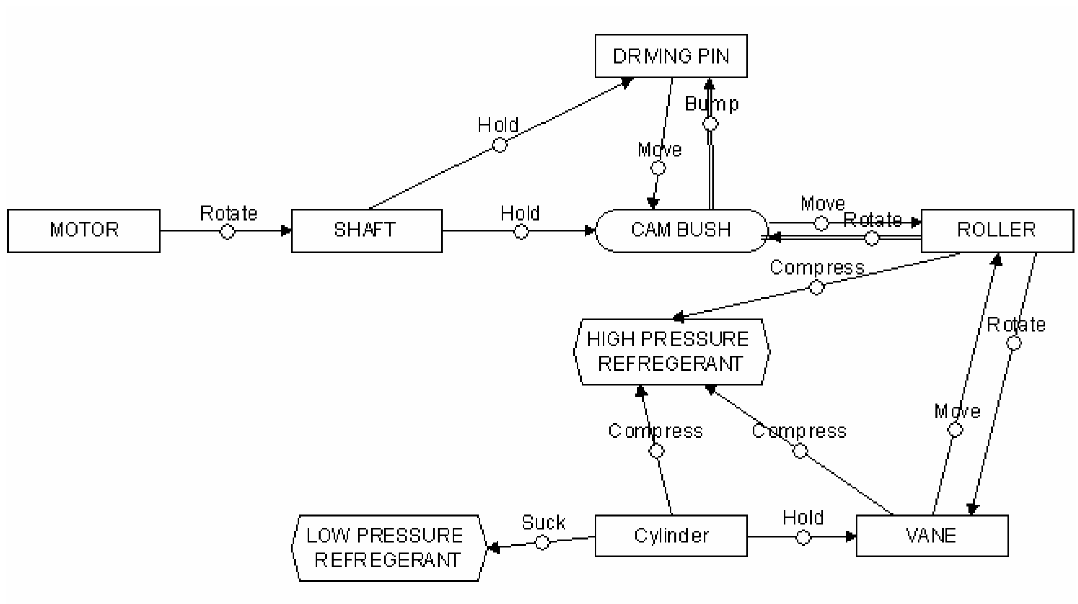

Figure 5. Function Block Diagram of Compressor with Old Design

rotational speed between the shaft and the cam-bush is influenced by the roller that is one of components to compose the compressing chamber in a rotary compressor. From the previous researches on the dynamics of a roller, it is well known that the rotational speed of a roller changes periodically according to the frictional forces generated by the vane and the shaft.

The figure 5 shows the function block diagram of ES compressor with old design. As shown on the figure, a speed change of the roller induces a bumping phenomenon. As a result, the driving pin bumps periodically with the cam-bush during the operation. Due to its structural characteristics having an idle cylinder and controlling the eccentricity by the rotational direction of the shaft, several challenges to secure the stability of the system arose. However, these challenges were addressed to the development of a new reliable latching mechanism, which is preventing the bumping phenomena between the driving pin and the cam-bush.

3. TECHNICAL CONTRADICTIONS

The next step of ARIZ illustrated in fig. 1 is transfer from the customer problem statement to formulation of the technical contradictions. A technical contradiction is a situation in problem solving where improving something in the system causes the deterioration of something else. The technical contradictions for latching mechanism are defined as follows;

The technical contradiction 1 is:
“If the driving pin is not connected with the cam-bush solidly, then the cam-bush is switched easily but driving pin is bumped with cam bush and destroys it.”

The technical contradiction 2 is:
“If the pin is connected with cam-bush solidly, then driving pin is not bumped with cam bush and does not destroy it but cannot switch cam.”

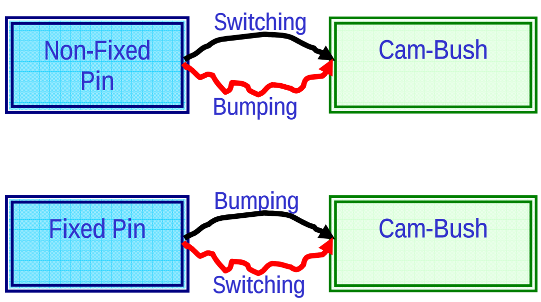

Figure 6. Schemes of TC1 (upper) and TC2 (lower)

The figure 6 illustrates technical contradictions 1 and 2 between driving pin and cam bush in the form of conflict schemes. Useful action (smooth line) of the pin to cam-bush is carried out at the same time with harmful action (curved line) in both of these schemes.

For our further analysis we selected technical contradiction 1 because this one provides the better realization of the main function of latching mechanism – switching. In our future concepts we will conserve switching as useful function and will remove bumping as a harmful function.

4. S-FIELD MODELING

Figure 7 shows the applied S-Field Modeling briefly: substance S1 is driving pin; substance S2 is cam-bush and field F1 is driving force between them.

Driving Pin S1 provides of the driving (useful function) double cam S2 during rotation and at the same time under influence summary force cam groove of cam S2 bumps with pin (harmful function) and these components are destroyed.

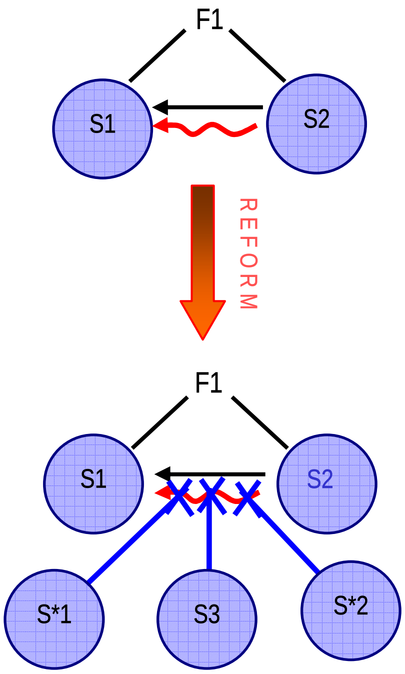

Figure 7. S-Field Modeling

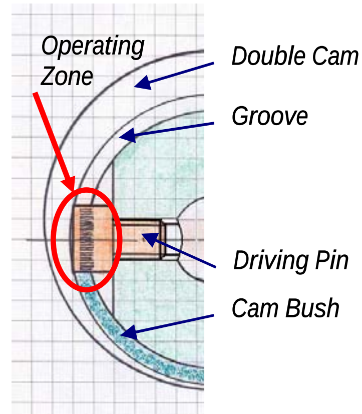

Figure 8. Operating Zone

As result of S-Field analysis and reformation of the initial S-Field model (in fig. 7 on top) into new S-Field models (in fig. 7 below) the next general directions for solutions have been obtained:

- Harmful interaction between S1 and S2 can be removed by introduction of new substance S3 between them;
- Harmful interaction between S1 and S2 can be removed by using of modified substance S*1 (Driving Pin);
- Harmful interaction between S1 and S2 can be removed by using of modified substance S*2 (Cam Groove);
- Combined direction contented mixture between the first , second and third directions.

The second and third directions are placed closer to ideality's requirements because in these cases new elements and fields have not been used. Thus obtained general directions will be used in the next steps of algorithm.

5. RESOURCE ANALYSIS

The main goal of this part of ARIZ is inventory of available resources, which may be used to solve problems. Operating Zone is an area of the conflict and includes driving pin and cam bush with a groove, illustrated in figure 8.

Operating Time is period during rotation and driving the double cam by pin.

To solve the contradictions, ARIZ recommends using the S-Field resources of the existent system in the first place.

Matrix of S-Field Resources:

		Substance	Field
Internal System	**Product***	Metal Cam-Bush (Groove)	Gravitation, Inertial Force
	Tool	Metal Pin	Driving Force
External System	**Super-System**	Shaft, Roller, Cylinder, Blade, Pressed Refrigerant	Driving Force, Inertial Force, Thermal Field, Different Pressure, Rotation, Summary Force between Shaft-Double Cam-Roller-Cylinder
	Environment	Atmospheric Air	Gravity Force, Geomagnetic Field, Atmospheric Pressure
	By-Product		

* - in the considered case there are no any limitations from the customer and so a pin and cam-bush can be a tool and a product by turns.

6. THE IDEAL FINAL TECHNICAL RESULT

An Ideal Final Technical Result is related to system or to mechanism as a whole. That statement is absent in classical ARIZ and it is used by authors in their practical implementation of the real projects [3].

The main purpose of this step and stement is an easy transfer to utilization of resources of super-system and environment (not only operating zone) for solving contradictions and inventive problem. Sometimes such solutions are becoming more acceptable for customer to application in the industry.

The Ideal Final Technical Result for the compressor can be expressed as follows: “Compressor itself provides the fixed connection between pin and cam bush without bumps during the shaft rotates and provides non fixed connection during switching without complication”

7. THE PHYSICAL CONTRADICTION

A physical contradiction is defined, which is the two mutual exclusive physical requirements to the same parameter of a component of the system.
The Physical contradiction is exactly related to connection parameter of a conflict pair “driving pin – cam bush” of a latching mechanism and is defined as follows:
“The connection between a driving pin and a cam-bush should be fixed for elimination of bums between them and the connection should not be fixed for switching rotational direction”.

8. THE IDEAL FINAL PHYSICAL RESULT

An Ideal Final Physical Result is related to operating zone, and particularly to tool or to its some part. This statement includes a physical contradiction and looks like short-cut physical model.

The Ideal Final Physical Result for the driving pin as Tool can be expressed as follows: "Driving pin itself provides the fixed connection between its and cam bush without bumps during the shaft rotates and provides non fixed connection during switching without complication"

9. SOLVING THE CONTRADICTION

The next part of ARIZ helps to resolve conflicts between requirements to parameters of a Tool guiding to a complete set of breakthrough solutions. As mentioned before these solutions should be placed from Ideal Results as close as possible. During solving process we will need to satisfy both sides of contradictions with minimal changes of latching mechanism and compressor on the whole. We will use resources in the next order: resources of operating zone (driving pin and cam bush) first for the nearest approach to the ideal physical result, then other resources of latching mechanism and after those resources of compressor (super-system) for the approaching to the ideal technical result.

10. SOLUTIONS

Use Resources of Operating Zone

How to approach to the Ideal Final Physical Result with using just components of operating zone driving pin/cam bush? For solving physical contradiction the most powerful principle of the separating contradictory requirements in space were applied.

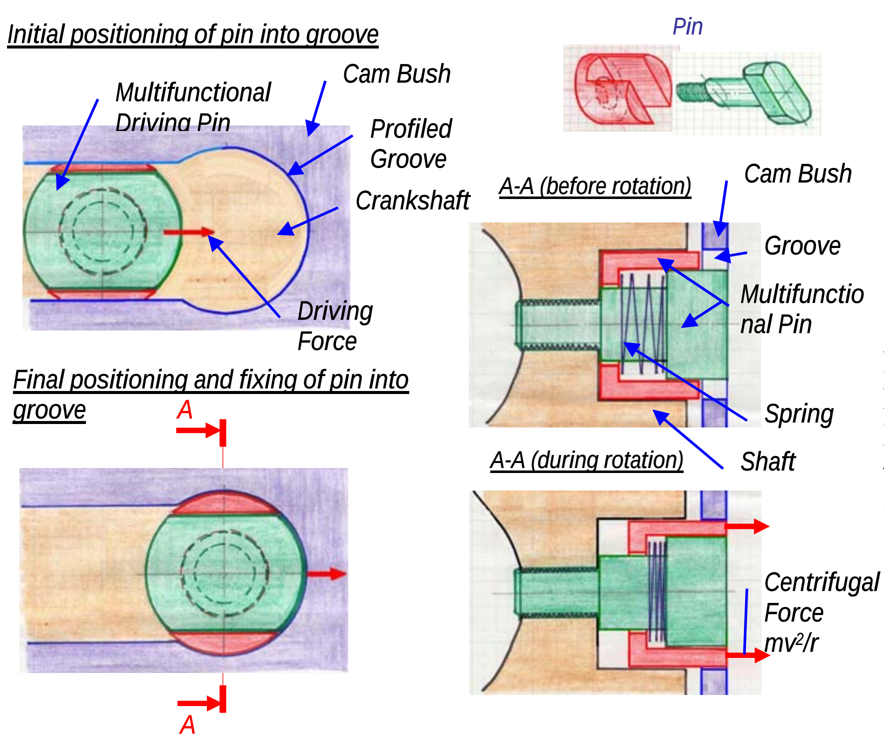

Figure 9. New design of the latching mechanism with the multifunctional pin

Going by this way logically it was proposed to separate the driving pin in two parts when one part provides fixed connection only during rotation and other part provides easy switching. So new driving pin includes two parts (figure 9). Inner pin part is fixed into shaft and connects by spring to outer mobile pin part which can move along pin axis. Under centrifugal force during rotation mobile part of the pin moves in radial direction and fixed cam bush through groove. During switching period centrifugal force is equal zero and mobile part of the driving pin under spring force moves inside shaft and disconnect pin and cam bush. The stiffness coefficient of the spiral spring is selected with considering the centrifugal force of mobile pin part at the operating speed.
Thus we applied in the proposed design combined pin and profiled groove into the cam bush that slightly complicates manufacturing and design itself in comparison with initial mechanism construction.

Therefore we can continue to use principle of the separation contradictory requirements in space for solving physical contradiction and further approaching to ideal physical result. It is proposed to separate initial one pin in the space and to use two ones for satisfaction different requirements.

The figure 10 shows the new construction of a latching mechanism with driving and fixative pins. Fixative pin is connected to shaft through flat spring and placed in the opposite direction of a driving pin. The stiffness coefficient of the spring is selected with considering the centrifugal force of fixative pin at the operating speed. As shown from figure 10 (upper section A-A), if the rotation of the shaft stops, the fixative pin enters inside of the shaft by the tension of the spring.

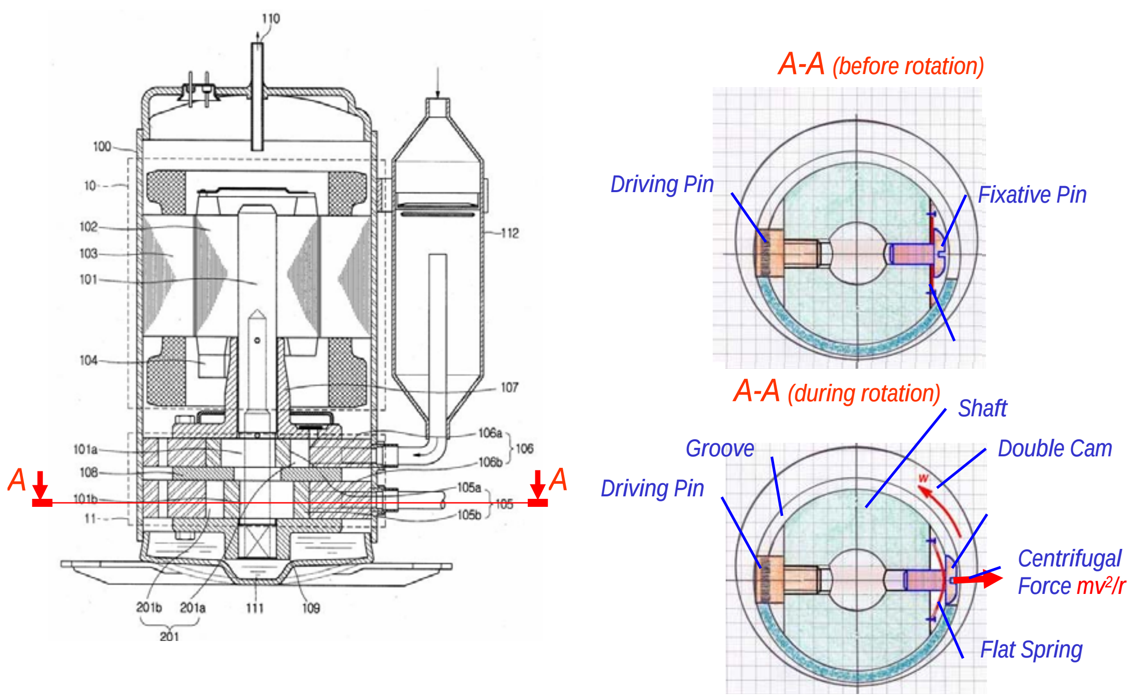

Figure 10. New design of the latching mechanism with driving and fixative pins

As a result the fixative pin does not hinder a rotational direction switch. On the other hand, if the shaft begins to rotate, the centrifugal force is bigger than the tension of the spring. As shown in figure 10 (lower section A-A) when the shaft rotates, the fixative pin projects to the outside of the shaft. The cam-bush is bounded with driving pin and the fixative pin and revolves with adhering to the shaft. Therefore bumping noise does not happen between a cam-bush and activated shaft.
So in these designs the centrifugal force of the shaft is used to solve the problem.
Building a newly diagram that includes the chain of the useful functions and the chain of

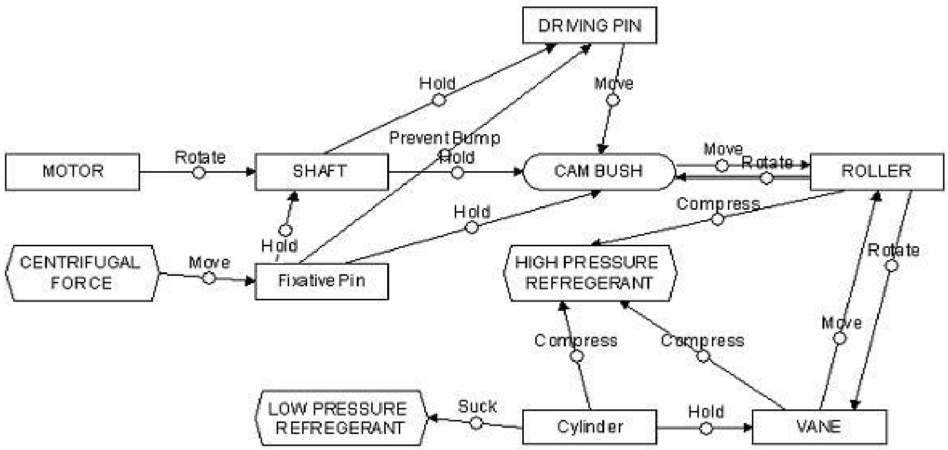

Figure 11. Function Block Diagram of Compressor with New Design

the harmful functions helps to understand the actual performance of the system, its basic function, and the conflict that is worth solving. The figure 11 shows the function block diagram of the ES compressor with new latching mechanism.

Use Resources of Super-System

Utilization of components of super-system i.e. compressor for solving contradictions helped us to develop other new designs with approach to the Ideal Technical Result.
The function block diagram for these designs represented in fig. 12 shows what kind of resource's field in our compressor's structure we can use for resolving problem related to bumping phenomena and destruction of pair “driving pin-cam bush”.

It is proposed to place lower cam and upper cam on the angle $(180-\alpha)^0$ (fig.13). In this case gap between upper (idle) cam and cylinder is inconstant one. During rotation on this cam different pressure acts and softly brakes double cam with force *Fgas*. This force presses cam bush to driving pin constantly and eliminates bumps.

Additionally in proposed design centre of gravity is displaced automatically. This one also provides of pressing of cam bush to driving pin and eliminates bumps. Dimension of the groove is decreased. And so other kind of bumps between pin and cam bush during switching process is removed as well.

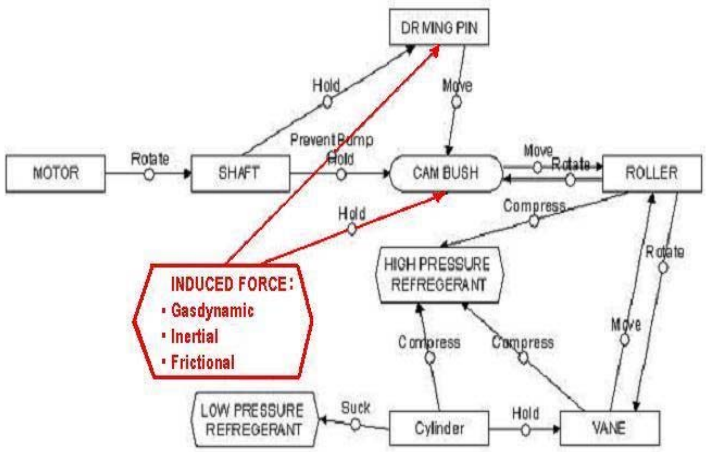

Fig.12. Function block diagram of compressor with new designs used resources of supersystem

Also proposed concept design (fig. 13) satisfies both parts of the contradiction and Ideal Technical Result, because compressor itself eliminates bumping and provides the fixed connection between pin and cam bush during the shaft rotation and provides non fixed connection during switching with minimum changes of the system.

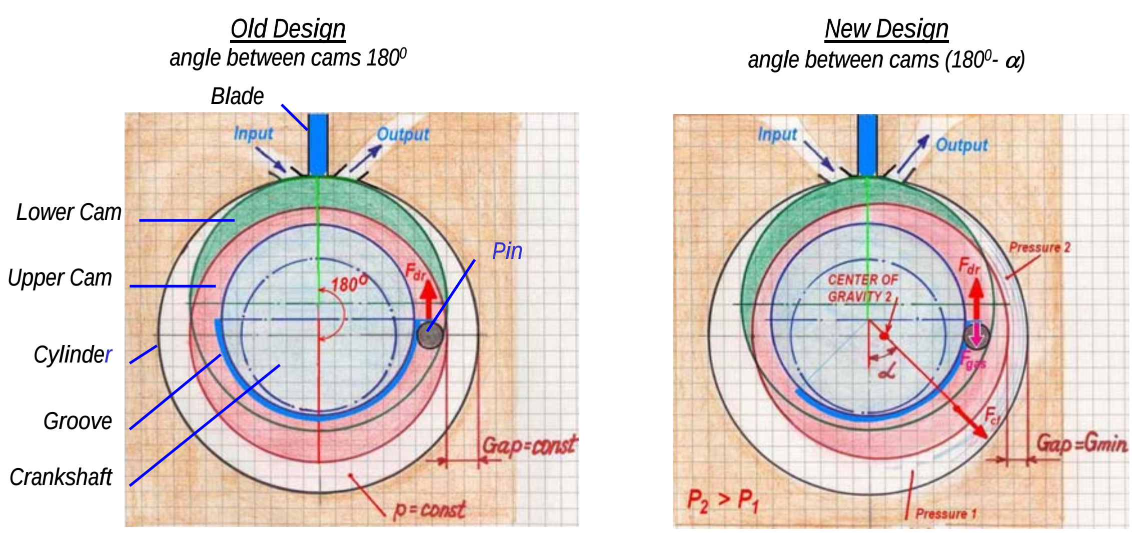

Figure 13. New design of the compressor with soft gas-dynamic braking

11. DESIGN CONCEPTS EVALUATION AND TEST RESULTS

After stage "Design Concept Generation" developed solutions have been considered and evaluated by customer. All concepts are ranked with application of three main criteria: adaptability for manufacture, estimated cost and patentability, indicated in table below.

Design Concept Evaluation

	CONCEPT SOLUTION	ADAPTABILITY	COST	PATENTABILITY
1	DOUBLE CAM AUTOFIXATION	High (+)	Low (+)	+
2	SOFT GAS-DYNAMIC BRAKING +	High (+)	Low (+)	+
3	MULTIFUNCTIONAL STOPPER	High (+)	Low (+)	+
4	ROLLER FIXATOR	High (+)	(0)	+
5	INCREASING DOUBLE CAM MOMENT OF INERTIA	Low (-)	High (-)	+
6	SECOND ADJUSTABLE PIN WITH FLAT SPRING	High (+)	Low (+)	+
7	SECOND ADJUSTABLE HOLLOW PIN	High (+)	Low (+)	+
8	MOBILE CENTRE OF GRAVITY	(0)	(0)	+
9	USING FLAT SPRING ONLY	(0)	Low (+)	+
10	FLAT SPRING STOPPER	High (+)	Low (+)	+
11	STOPPER WITH PERMANENT MAGNET	High (+)	Low (+)	+
12	BALL FIXATOR	High (+)	Low (+)	+
13	DOUBLE BALL FIXATOR	(0)	(0)	+
14	PROFILED FIXATOR	(0)	(0)	+
15	BRACKETLESS BALL FIXATOR	(0)	(0)	+
16	MULTIFUNCTIONAL STOPPER WITHOUT SPRING	(0)	(0)	+
17	OUTPUT PRESSURE UNIFORMITY VS BUMPS	Low (-)	High (-)	-
18	THREE CHAMBER COMPRESSOR	Low (-)	High (-)	-
19	ENLARGED PRESSURE ANGLE VS BUMPS	High (+)	Low (+)	+
20	ANGULAR BLADE ARRANGEMENT	High (+)	Low (+)	+
21	REVERSE DESIGN	Low	(0)	-

The first three design concepts have been accepted for tests and manufacturing utilization with international patent applications [4, 5, 6]. These design concepts were described in article above. Other concepts have been combined in 6 Korean national patent applications [7-12]. Three concepts (17, 18 and 21 concepts in the table) have not been accepted customer for tests and application because they change initial compressor's structure design and further manufacturing process seriously.

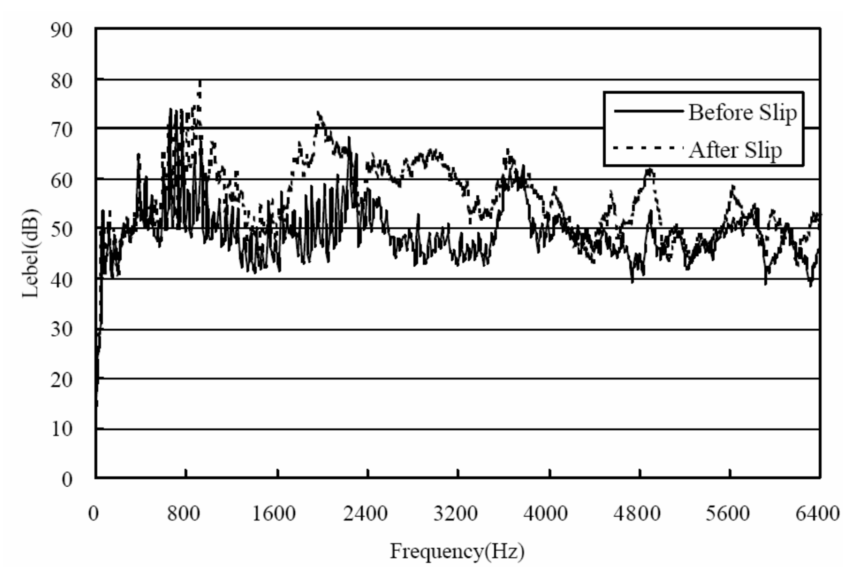

Figure 14. Comparison noise level for old and new compressor design

The figure 14 compares test results of the noise spectrum of ES compressor with and without adopting the new latching mechanism. The dashed line represents the noise spectrum of ES compressor without latching mechanism, and there are some peaks for bumping noise are observed. And the solid line represents new developed ES compressor. As shown from the figure, the bumping noise is not generated. Thus from the test results of ES compressor with the new latching mechanism, it is shown that the abnormal bumping phenomenon induced by the collision between the cam bush and the driving pin has been successfully eliminated.

12. CONCLUSIONS

In the article we introduced the applied Algorithm of Inventive Problem Solving (ARIZ) which has been employed in the daily practical activities for analysis and solving the real industrial projects. It is proposed to use some new approaches and statements for reforming initial task in the line of the future solutions. The different new designs of the compressor and latching mechanism have been developed with the aid of applied ARIZ.

The specific results of this work obtained with using considered ARIZ tools are development of 21 concept solutions for described problem which were combined in 9 international and national patent applications [4-12] and introduction of some of them in mass production of the company. The annual income from that introduction was about $10,000,000. The results of this project were granted the Samsung Achievement Award in 2003.

This project was implemented by authors in TRIZ Group on demand of Compressor Division of Samsung Electronics and authors deeply appreciate Mr. Jin-Kyu Choi from this division for his kind assistance and unselfishness.

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