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Araştırma Makalesi Research Article

CONCEPTUAL DESIGN OF A TRANSPORT MACHINE FOR CONVEYING BALL-LIKE MATERIAL

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Keywords
Systematic Design, Continuous Transport, Ball-Like Material, Requirements List.

Abstract
Conveying of granular material in the manufacturing process is quite common. The transport system design directly affected by the properties of the material and the transport conditions. Grainy materials can be transported not only by mechanical methods such as belt, screw, bucket and so on but also by pneumatic and hydraulic systems. It is a general requirement for the conveying equipment to allow both horizontal and vertical conveying to be able to transport the material with minimum energy cost. The main goal of this work is to design a special machine which transports ball-like materials from one source to another. The well-known systematic design approach is used to reach the optimum design satisfying design constraints. This design process includes clarify the task (problem definition), conceptual design (establish solution principles), embodiment design (achieve concept variants and selection) and detail design of selected variant. In present study, by following systematic design approach, a transport machine with a rotary plate was designed.

KÜRESEL FORMDA MALZEME TAŞIYAN BİR TRANSPORT MAKİNASININ KAVRAMSAL TASARIMI

Anahtar Kelimeler
Sistematik Konstrüksiyon, Sürekli Transport, Küresel Malzemeler, İstekler Listesi.

Öz
İmalat sürecinde granül malzemenin taşınması oldukça yaygındır. Taşıma sistemi tasarımı, malzemenin özelliklerinden ve malzemenin taşıma koşullarından doğrudan etkilenir. Granül haldeki malzemeler sadece kayış, vida, kova vb. mekanik yöntemlerle değil, pnömatik ve hidrolik sistemlerle de taşınabilmektedir. Malzemenin minimum enerji maliyeti ile taşınabilmesi için taşıma sisteminin hem yatay hem de dikey taşımaya izin vermesi genel bir gerekliliktir. Bu çalışmanın temel amacı, bilye benzeri küresel formdaki malzemeleri bir hazneden alarak belirli uzaklıktaki diğer bir hazneye taşıyan özel bir makine tasarlamaktır. Bu amaçla sistematik konstrüksiyon yaklaşımı kullanılarak farklı konsept çözümler araştırılmıştır. Sistematik konstrüskiyon yaklaşımı, tasarım kısıtlamalarını karşılayarak en uygun tasarıma ulaşmakta kullanılan en iyi yöntemdir. Bu tasarım süreci, ödevin açıklık kazanması (problem tanımı), kavramsal tasarımı (çözüm ilkelerini oluşturma), çözüm önerilerinin oluşturulması (alternatif tasarımlar ve seçimi) ve seçilen alternatifin detaylı tasarımını içerir. Sunulan çalışmada, sistematik konstrüksiyon süreci izlenerek dokuz faklı çözüm oluşturulmuş, fayda değer analizi sonucunda ödevi en iyi şekilde yerine getiren döner plakalı özel bir taşıma makinesi tasarlanmıştır.

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1. Introduction

Automation of many processes in various industrial fields such as, military, food and beverage, electronics, manufacturing, materials handling etc. is very common in todays' industry. Correspondingly, transport of a product or semi-product from on site to another with reliable and quick way gains importance. In the case of a liquid or a gas, it is possible to use piping systems to transport these fluids to where these are required. But in the case of solid granular materials having certain geometry and dimensions, the task is not as easy as it looks.

The review of industrial application reveals that the need for transportation of ball-like materials from sport goods to food is very common. For example, in the case of tennis or golf balls, the ball-like materials should be transported not only in sports activities, but also in production process (Langer et al., 2007; Sawallich, 1998). Furthermore, in food and beverage industry, products are packed after many processes from harvesting to final market. At the same time, sizes and rigidity of each food can be different. These food products either can be directly sorted to various sizes or can be transported to produce fruit juice etc. (Carroll, 1984; Altman et. Al., 1978). Another application in machine industry is the manufacturing and mounting of balls of rolling element bearing (Chang, 2006; Tsuchimochi et. al., 2015; Wijngaarden, 2004). As mentioned above, since the physical properties and manufacturing need of materials change depending on specific application, a transportation solution is required in order to move ball-like semi-products from one station to another.

In this paper, it is aimed to design a new transport machine to be used in the conveying of spherical semi-products using a systematic design approach. In order to reach all possible solutions, the given task should be defined very well. For this reason, the design requirements of the given task were determined and the physical principles that could be used to developing various solutions are listed. Then, three different concept design solutions were obtained. After that, the selection process of optimum design based on technical and economical evaluation was carried out. In conclusion, detailed design of optimum solution is presented.

2. Systematic Design Approach

The Industrial Revolution in the 19th century caused the acceleration of mechanization. As a result, sufficient strength, sufficient hardness, low wear and friction, ease of use, ease of manufacture and assembly began to gain importance in machine design (Redtenbacher; 1859). The optimum design solution that meets these demands can only be obtained by methodical approach. The idea of systematic design first put forward in early1900's (Erkens,1928), and the efforts for implementing this idea to design activities gained importance after World War II. (Kesselring, 1942; Tschochner, 1954; Niemann, 1975; Matousek, 1957; Leyer, 1963; Pahl et al., 2007; Kroes, 2002; Haik et al., 2011). Nowadays It is widely used in industrial applications as an innovative design approach (Parlar et. al, 2017; Börüklü et al., 2017; Börüklü et al., 2018; Bozdemir et al., 2001; Şekercioğlu, 2019). The systematic design approach is a very effective method to embody the design and production process. It provides both original and reusable solutions with a step-by-step study. In this way, solution principles are embodied step-by-step by separating the technical system into as simple sub-systems as possible, making it possible to achieve and optimize the solution with a smaller amount of effort in the early stages of the design.

There are several suggested systems which vary in detail but are basically similar (Pahl et al., 2007; Koller, 1979; Roth, 1982; Anon.,1987). The basic process consists of four steps. In the first step, the task is defined. In conceptual design, a function structure is obtained and solution principles are searched according to the requirements list. Afterwards, preliminary layout is performed and evaluated based on technical and economic criteria during embodiment design stage. Finally, detail design is completed with detail drawings and production documents.

3. Task Clarification

In the systematic design approach, the problem is discussed in its most general form. Thus, it allows to obtain solution methods more easily by looking at the problem from a wider perspective. In this study, the problem is defined as follows *"Ball-like material will be transported from source container which is full of these elements to an empty container which is at least 500 mm far away from the source"*.

According to G. Pahl and W. Beitz (Pahl et al., 2007), in order to reach the most appropriate solution, the requirements list should be first prepared that clearly sets out the design expectations. When preparing the requirements list, the all demands from costumers should be taken into account. Dimensions, geometric forms and related standards should be clearly defined. It is obvious that these requirements are necessary for the conceptual design process. These requirements can be flexed or modified as needed during the later stages of the design. Emerging requirements should be defined either as demands that must be taken into consideration for all circumstances or wishes that can be fulfilled to the extent permitted by the technological and economic conditions. Requirement list of the problem is given in Table 1.

Table 1. Requirements List

	Demands
1	Materials to be transported are ball-like parts having maximum 10 mm in diameter
2	Ball-like materials will be placed on a standard container.
3	Ball-like materials can be captured from the container in all possible ways.
4	Depth of the container is maximum 200 mm.
5	Ball-like materials will be transported to target container at least 500 mm far away from the source container.
6	During the transport ball-like materials should be sorted regarding their sizes
7	There is no material restriction for ball-like elements.
8	There should be no discontinuity during transportation.
9	The total cost of the system should be lower than 10 000 $
	Wishes
1	Remote control may be applied to system
2	Mobility of the system is desirable.
3	Automatic stop for empty container may be considered.

4. Conceptual Design

The systematic design approach is always based on a gradual progression from the abstract to the concrete in line with a goal. For this reason, the requirements list consisting should be reduced to the level defined as "basic principle" or "basic function" by abstracting as much as possible without losing its essence. The term *function* can be used to describe the intended input/output relationship of a system. Thus, the function becomes a concise form of the task, independent of any specific solution. If the overall task has been clearly defined then it is possible to specify the *overall function.* In this study, the overall function is *transportation ball-like material one source to another.*

The overall function is still in its most abstract and complex form. In order to achieve a more non-figurative structure, the first step to be put forward is to define the overall function by dividing it into sub-functions. Therefore, at this stage, it can be said that the design activity is at the intellectual level. It is tried to reach a solution step by step by separating the technical system into simple subsystems as much as possible. It is possible to continue this analysis step by step and go down to the simplest sub-functions, which are no longer practical to simplify. According to overall function, ball-like material should be captured firstly and the source should be fed with the material continuously. After that, the material should be conveyed, sorted and then left to the targeted point. Figure 1 shows the functional structure of given task. As shown, Energy (electrical and/or mechanical), and Material enter the system and emerge as material as a result of the overall function. For this specific task outlined above, sub functions are determined as capturing, conveying, sorting and discharging. Each sub-function is related to each other depending on the basic function. Thus, a large number of variants can be obtained by combining the solutions that implement each sub-function in different ways.

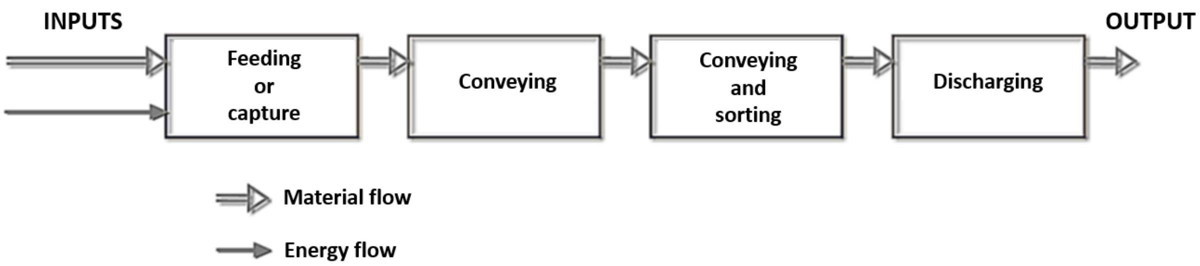


Figure1. Functional Structure

For ball-like material transport task, the solutions satisfying feeding or capturing elements sub function can be as follows: mechanical picker for capturing materials, rotary vane, rotary table, Coulomb friction or pressurized air.

Similarly, working principles used for conveying are transport screw, belt, rotary table, friction, hydraulic or pneumatic. Discharging sub function can be satisfied with gravity in the simplest way (Gavin et al., 2013).

Solutions that will fulfill the overall function can only be achieve by combining the working principles into a working structure. That is, the system must be synthesized. In Table 2, the conceptual variants (V) arranged for working principles for fulfilling each sub-function are shown. As a result of the combinations of solutions satisfying all sub-functions yields 9 different conceptual variations. At this stage, it will be more realistic to continue design with a much limited variations instead of all 9 different solutions. For this purpose, using a binary evaluation chart can be useful. This method can be used for *rough comparison of solution variants* evaluation. It can be used where "objective" parameters can be expressed with a certain accuracy and can be assigned precise values. The alternative is a rather rough evaluation based on the selection of the best solution for the given variant, where certain evaluation criteria are applied to two variants at the same time. The scores are entered into a so-called *dominance matrix.* Accordingly, the alternative that better meets the "objective" parameters than the other is evaluated with one and the other with zero. It is possible to create a ranking from the sum of the values taken by each variant. Applying binary evaluation method as shown in Table 3 yields 3 different solutions which give likelihood of success. The promising solutions are V5, V6 and V7.

Table 2. Possible Combination of Working Principles to Achieve Concept Variants

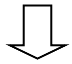
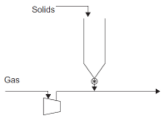
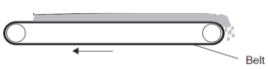
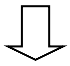
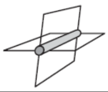
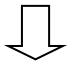
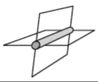
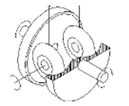
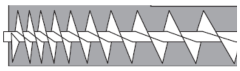
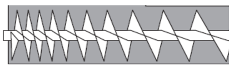
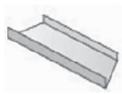
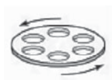
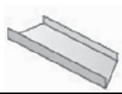
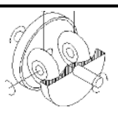
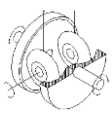
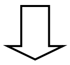
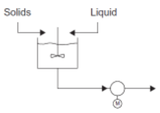
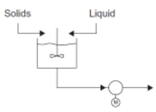
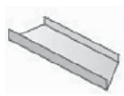
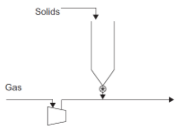
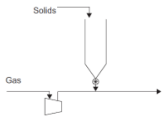
Concept Variants	Feeder	Conveyer	discharger
V1			
V2	 Vacum		
V3			
V4			Convertion energy (potention to kinetic)
V5			
V6			
V7			
V8			
V9	 Blowing	 Blowing	energy convertion (fluid to kinetic)

Table 3. Binary Evaluation of Solution Variants

	V1	V2	V3	V4	V5	V6	V7	V8	V9
V1	-	1	1	1	1	1	1	1	1
V2	0	-	1	1	1	1	1	1	1
V3	0	0	-	1	1	1	1	0	0
V4	0	0	0	-	1	1	1	0	0
V5	0	0	0	0	-	1	0	0	0
V6	0	0	0	0	0	-	0	0	0
V7	0	0	0	0	1	1	-	0	0
V8	0	0	1	1	1	1	1	-	1
V9	0	0	1	1	1	1	1	0	-
TOTAL	0	1	4	5	**7**	**8**	**6**	2	3

5. Embodiment Design

At this stage, it is possible to draw selected alternatives with simple drawings that explain the working principle. These are conceptual sketches and do not include details. Sketches are used as the first presentation of the target design. These sketches should also provide information on details that may be needed later. The assembly of mechanisms that perform sub-functions will provide a visual conceptualization of alternatives and be presented to the customer. The conceptual sketches of the satisfied solutions are shown at Figure 2. As shown in the Figure, capturing and conveying functions are achieved by using transport screw, rotary table and coulomb friction in conceptual variants.

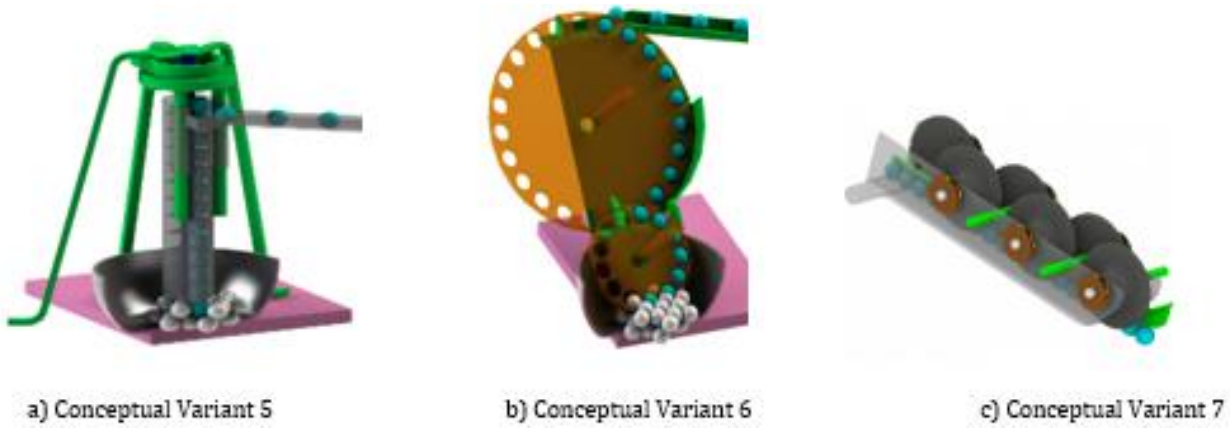


Figure2. Conceptual Sketches of Ball-Like Material Conveying

5.1 Evaluate Against Technical And Economical Criteria

Evaluation means to determine the usefulness or strength of the alternative solutions for a particular objective. A comparative evaluation will be made by considering how well the three different solutions obtained as a result of the functional synthesis carried out respond to the determined objectives. The result in evaluating a solution is not absolute. However, a comparison can be made in terms of whether it satisfies the requirement list. Accordingly, it is a rating made in the form of a comparison between an imaginary ideal solution and a conceptual design while making an evaluation.

The fundamental issues to be compared between the conceptual variants are listed as follows:

- Simplicity
- Energy efficiency
- Function reliability
- Ease of manufacturing
- Cost

It can be difficult to determine actual cost figures during the conceptual design phase. For this reason, it is often not possible to establish an *economic rating* R_{eco} on production costs. However, the technical and economic aspects can be more or less qualitatively defined. Technical and economical evaluation of the remaining conceptual variants are given in Table 4 and Table 5, respectively. According to VDI 2225, each objective is scored between 0 and 4 (Anon.,1987). Zero indicates that the solution is insufficient to meet the desired objective, and 4 indicates that it meets the objective in the best way. The absolute value scale makes it very easy to tell whether a particular variant is relatively close or far from the theoretical ideal. It is therefore generally more suitable for comparison.

Accordingly, score is assigned to the variant taking into account each objective. The degree of appreciation is determined by dividing the total score of the variant by the ideal score.

Table 4. Technical Evaluation of The Remaining Principle Solution Variants

Technical Criteria	**Variants**		
	V 5	**V 6**	**V 7**
Simple operation	4	4	4
Functional reliability	4	4	2
Ease of manufacturing	2	3	3
Simplicity	3	4	2
Energy efficiency	2	3	2
Total	15	18	13
R_{tech}=Total/20	**0,75**	**0,9**	**0,65**

Table 5. Economical Evaluation of The Remaining Principle Solution Variants

Economical Criteria	**Variants**		
	V 5	**V 6**	**V 7**
Low material cost	3	4	2
Low assembly cost	4	3	2
Possibility of manufacturing in own workshop	4	4	4
Low machining cost	2	3	3
Total	13	14	11
R_{eco}=Total/16	**0,81**	**0,88**	**0,7**

The straight line method based on the arithmetic mean - $R=(R_{tech}+R_{eco})/2$- can be used to determine which of the variant evaluated technically and economically is closer to the ideal one. The conceptual variant 6 is the best alternative for the ball-like material conveying with a weighted rating of 89%. If the solution variant is rated below 60%, it is not eligible for further development. The variant with a rating above 80% can usually be moved into the detail design phase without further development.

6. Detail Design

The detailed design process covers all the steps from the shaping of all the parts that make up the machine to the material selection, from the manufacturing method to the cost. In this study, the three-dimensional model of the transport machine created with the Solid Works software as shown in Figure 3. The motor drives both the capturing and the conveying plate synchronously with the aid of a belt-pulley in a 1:2 velocity ratio. The motor rotates at 1000 rpm. A timer belt is used to ensure synchronization. The direction of the rotary tables is counterclockwise as shown in the Figure 3. It is considered that the rotary tables will be manufactured from metal sheet. The thickness of the plates was taken as 4 mm. The slot diameter is 10 mm as specified in the requirement list. There are 12 slots in the capturing plate, 24 slots in the conveying plate. Container depth is specified as max 200 mm in the requirement list. Therefore, the diameter where the slots are placed on the capturing plate is determined as 180 mm. As the rotary table passes through the source container to collect ball-like materials, ball-like materials are placed in the slots on it. Since the balls with a diameter larger than 10 mm cannot be placed in the slots, the balls of the desired size will move forward with the rotation of the capturing plate and then reach the conveying plate. A fixed plate is placed behind the rotary tables and its width is taken as the radius of the rotary tables. The positions of the plates and the working principle of it are shown in more clearly in Figure 2b. There is a 1 mm gap between this plate and the rotary table. In this way, the captured ball is transported upwards with the rotary table such as bucket elevators without squeezing or falling. From here, ball-like materials are left on the ramp. The ramp is designed as an 11 mm wide groove to sorting ball-like material. So the balls will be rolled with the help of gravity and transported to the empty container at a distance of 500 mm. Thus, ball-like materials sorted according to their sizes are transported to the desired point quickly, precisely and safely as described in the task. At the same time, the obtained design has been allowed the material to be transported in both horizontal and vertical directions.

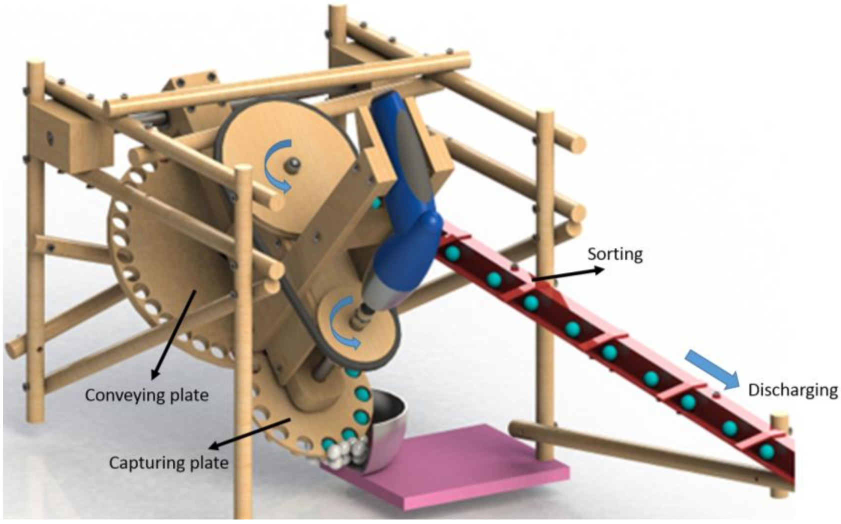


Figure 3. The Three-Dimensional Model of The Device

7. Conclusion

The systematic design phases that presented by Gerhard Pahl and Wolfgang Beitz were applied to create new conceptual designs for a completely new problems (Pahl et al., 2007). The problem and limitation were defined. The requirements list was prepared to show the expectations from the design. Function structures containing the working principle of the device was created and the conceptual variants were revealed using the certain methods. In this way, nine different solution suggestions were obtained. In order to reduce the number of solution suggestions, the pairwise comparison method, which is a rough evaluation, was applied to these nine solution variants. Thus, the number of alternative concept designs has been reduced to three. Evaluation objectives were created by considering the requirement list and most appropriate conceptual design was selected depending on the technical-economical evaluation. The detail design of the device was developed. The procedure for the systematic design approach was strictly followed and this effort yielded completely original solutions some of which are practically applicable. It is shown that the systematic design approach provides the reach all possible alternative solutions to a well-defined problem quickly and easily. Therefore, it can be said that it is very effective in identifying, solving and developing products, especially in the preliminary design process.

Conflict of Interest

No conflict of interest was declared by the author.

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