Prospectivity of designing roller supports for conveyor systems operating in harsh conditions

Bolat Askerbekovich Manezhanov[1], Yerzhan Yarnarovich Shayakhmetov[1], Toqtasyn Mendebayevich Mendebayev[1], Omar Temirtasovich Temirtasov[2], Rysbala Razakpayevna Ibragimova[2], Yermek Tolegenovich Abilmazhinov[2], Samat Mukhametkaziyevich Mansurov[2]

[1]Kazakh National University named after Satpayev, Satpayev Street, 22a, Almaty, 052213, Kazakhstan
[2]Semey State University named after Shakarim, GlinkiStreet, 20A, Semey, 070012, Kazakhstan

Abstract. This article describes morphological classification of roller supports in conveyor systems with development of a General Definitional Table (GDT). This work is aimed at facilitating work of the engineering designer. Basing on engineering forecasting, the prospectivity of proposed designs of roller supports operating in severe conditions was analyzed. Comprehensive experimental and theoretical study of various inventions made it possible to develop fundamentally new designs of roller supports for conveyor systems. Inventions have been confirmed by provisional patents of the Republic of Kazakhstan, details whereof are shown below in tabular form.
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Introduction

In industry, conveyors and conveyor systems are widely used with roller supports acting as basic elements that define performance, power consumption and fire safety and affect durability. Cost of a roller supports is 25-30% of the total cost, and roller supports account for over 40% of all maintenance and repair costs. [1, 2].

The basis of engineering forecasting in development of General Definitional Table (GDT) is a triad: reliability and durability of parts and assemblies taken into account during the design; manufacturing quality; successful operation ensured by timely maintenance. The GDT is made taking into account the morphological classification of roller supports in conveyor systems used worldwide (Table 1).

Table 1. General definitional table (GDT) of roller supports design features

Item	**Characteristics of a patent solution - $\varphi(i)$**	Rating	
		Base	Proposed
1	2	3	4
1. Technical excellence of the design $\varphi(1)=1$			
R1	Roller body does not provide for simultaneous misalignment of built-in outer ring and sealing elements related to the inner ring of bearings and sealing elements placed on the deformed axis or deformed semi-axes	1	1
R2	Partial simultaneous misalignment is ensured for bearing rings and sealing elements due to mechanical compliance of the hub or the outer rubber-metal cage of the bearings	2	2
R3	Partial simultaneous misalignment is ensured for bearing rings and sealing elements due to mechanical compliance of hubs and the sidewall	3	3
R4	Simultaneous misalignment is ensured for bearing rings and sealing elements due to self-aligning bearing units in parallel planes	4	4
R5	Simultaneous misalignment is ensured for bearing rings and sealing elements due to self-aligning bearing units with predefined trajectory in a common aligned plane	5	5
2. Degree of novelty $\varphi(2)=1$			
R1	Improvement of parts of existing engineering designs	1	1
R2	Improvement of sealing devices of bearing assemblies in existing engineering designs	2	2
R3	Improvement of the entire existing bearing assembly at a new technological level	3	3
R4	New technical solution that complements existing patent solutions	4	4
R5	Fundamentally new solution that has the meaning of an invention in this area	5	5
3. Roller support reliability $\varphi(3)=0{,}75$			

R1	Does not satisfy requirements for reliability, durability, conservability and maintainability	1	0.75
R2	Satisfies one of the four listed requirements	2	1.5
R3	Satisfies two of the four listed requirements	3	2.25
R4	Satisfies three of the four requirements	4	3.0
R5	Satisfies all four requirements	5	3.75
4. Cost-effectiveness of the design $\varphi(4) = 0{,}5$			
R1	Does not satisfy the requirements of ease of manufacturing, standardization, ease of maintenance and repair	1	0.5
R2	Satisfies one of the four requirements	2	1.0
R3	Satisfies two of the four requirements	3	1.5
R4	Satisfies three of the four requirements	4	2.0
R5	Satisfies all four requirements	5	2.5
5. Environmental compatibility of the engineering design $\varphi(5) = 0{,}31$			
R1	Does not satisfy requirements for quietness, bearing assemblies protection from clogging, absence of grease leaking, bezoplenochnosti rolling elements	1	0.31
R2	Satisfies one of the four requirements	2	0.62
R3	Satisfies two of the four requirements	3	0.93
R4	Satisfies three of the four requirements	4	1.24
R5	Satisfies all four requirements	5	1.55

There are about a hundred forecasting methods [3, 4, 5, 6, 7, 8]. In our work we used such methods as the Theoretical Solution of Inventive Tasks (TSIT) and the Theory of Double Variables [9].

Methods

Forecasting based on patent sources consists of the following operations: preparation of GDT; comparing patents with GDT and defining Invention Recall Factor.

The Invention Recall Factor r characterizes the probability of commissioning new machinery and the potential technical level of the anticipated object:

$$r = \frac{q}{q_{\max}} = \frac{\sum_{1}^{n} j \cdot \varphi(i)}{n \sum_{1}^{n} \varphi(i)}, (1)$$

where q is actual sum of assessments received in course of comparing the patent with the GDT, and $q_{\max}$ is the maximum sum of assessments taken from the characterization matrix.

In whole, coefficient r is a generalized index that makes it possible to estimate the engineering and technical relevance of new solutions presented in non parametric sources (patents). Calculation of coefficient r makes it possible to sort and identify (prospective design of) really valuable inventions and to perform further prediction on them. Values of the Invention Recall Factor are within the following limits: $0.2 \le r \le 1$. Viability of the engineering solution is higher when it approaches unity. Deficiency or reserve of further improvement of the invention is defined by $d = 1 - r$.

Roller supports, depending on their level of perfection, are divided into five technical complexes. With coefficients r using semantic categories and scoring system taken from basis matrices, we obtained conventional compliance that quantitatively reflects synthesis of patent information. Attestation scale has been obtained from traditional five-point evaluation (Table 2).

Recall Factor of a Single Invention or a technological complex is the main criterion for engineering prediction. This criterion defines the reduced number of patents, generalized recall factor and the optimum strategy of a technical system.

Table 2. Scale of assessments of predicted efficiency of technical solutions in case of using non-parametric information sources

Coefficient of invention project (intensity of local strategy)	Predicting viability		Category of prediction
	Semantic assessment	Assessment level	
1.00 ... 0.93 0.92 ... 0.86 0.85 ... 0.80	Very promising	Upper Middle Lower	I up I mid I low
0.79 ... 0.73 0.72 ... 0.66 0.65 ... 0.60	Promising	Upper Middle Lower	II up II mid II low
0.59 ... 0.53 0.52 ... 0.46 0.45 ... 0.40	Little promising	Upper Middle Lower	III up III mid III low
0.39 ... 0.20	Unpromising	-	IV

Indicated number of patents M_n characterizes technical potentiality of competing groups presented by N_n patents:

$$M_n = \sum_{1}^{K=N_n} r_K, (2)$$

here r_K is the recall factor for inventions selected by functionally homogeneous characteristics.

Generalized recall factor of invention r_1 characterizes the likely level of technology in the perspective and has the form:

$$r_1 = \frac{1}{N_n} \sum_{K=1}^{K=N_n} r_K \eta_K \ ,(3)$$

here N_n is the nominal number of patents; η_K is the frequency of a patent getting into a certain statistic class; r_K is the coefficient of a single patent.

r_1 is based on analysis of a random value of sources of information distribution by statistical classes, and r_2 is based on deterministic assessment of trends (information flow) related to the nominal and reduced flows of patent information.

In practical calculations, a modified generalized invention recall factor r_2 is used, which is the ratio of the reduced flow of patent information- $M_n(t)$ to the nominal $N_n(t)$ number:

$$r_2 = \frac{\lim\limits_{\delta \to 0} \sum\limits_{a}^{b} M_n(t) \cdot \Delta t}{\lim\limits_{\delta \to 0} \sum\limits_{a}^{b} N_n(t) \cdot \Delta t} = \frac{\int\limits_{b}^{a} M_n(t) \cdot dt}{\int\limits_{b}^{a} N_n(t) \cdot dt} \text{ where}$$

by, $|\Delta t| < b$ (4).

Main part

Ways of improving conveyors, storages, elevators and palletizers with roller floor feature development of main designs of roller supports in five directions. The majority of patents since the 20-ties of the last century are roller supports with rigid body (K1). Since 1935, roller supports with special bearings appeared (K2). After World War II, roller supports with hubs made of rubber and combined materials started to be introduced (K3) [10].

Rollers with thin sidewalls and shaped elastic hubs (K4) were developed for light and medium loads (see Table 3).

The need for reliable transportation of heavy and super heavy loads required creating roller supports of new design. Development of rollers with self-aligning bearing units (K5)

Table 4 shows the list of patents and invention certificates in roller design (K5) and Invention Recall Factors - *r* are identified, category of viability prediction. Four types of curves were built that show distribution of information sources depending on time (fig. 1). Curves 1 and 2 serve for general characterization of generating new technological ideas, and curves 3 and 4 serve the purpose of defining the generalized invention recall rate and characterize viability of a certain design.

Table 3. Roller support with shaped thin sidewall elastic hubs K4

No.	Initial data: Country, patent number, certificate of invention, class, subclass, date of publication	Number of designs in the patent	Base assessment i_1	i_2	i_3	i_4	i_5	q_{max}	q	recall factor r	Category of prediction
1	2	3	4	5	6	7	8	9	10	11	12
1	Roller support made by French company "Galle" with Z-shaped thin hubs, designed in the 70-ties	1	2	2	3	4	3	17.8	8.9	0.5	3med
2	West Germany application # 2724243, IPC B 65 G 39/07, 1978	1	2	3	5	5	4	17.8	12.4	0.70	2 med
3	Invention Certificate of the USSR # 668853, IPC B 65 G 39/06 applied 07.02.1978, # 2577509, published 25.06.1979	1	2	3	4	4	4	17.8	11.4	0.64	2low
4	West Germany patent # 2512843, IPC B 65 G 39/07, published 1979	1	1	2	3	4	3	17.8	7.8	0.44	3low
5	England patent # 1566124 IPC G 39 B 65/02, 30.04.1980	1	2	3	3	4	3	17.8	9.97	0.56	3h
6	France application # 2437545, cl. F 16 J 15/447, 25.04.1980	1	1	4	4	4	4	17.8	11.4	0.64	2low
7	England application # 2047845 IPC B 65 G 39/09, 03.12.1980	1	2	3	4	4	4	17.8	11.4	0.64	2low
8	USA patent # 4311242, cl. B 07 1/14, 19.01.1982	1	1	2	3	4	3	17.8	7.8	0.44	3low
9	Japan application # 57-126311, IPC B 65 G 39/08, 06.08.1982	1	2	3	4	4	4	17.8	11.4	0.64	2low
10	USA patent # 4448296 IPC B 65 G 13/00, 15.05.1984	1	2	3	4	4	4	17.8	11.4	0.64	2low
11	United Kingdom application # 2180035, IPC B 65 G 39/00, published 18.03.1987	1	1	4	4	4	4	17.8	11.4	0.64	2low
12	Invention Certificate of the RF # 1542872A1, IPC 5 B 65 G 39/00, 15.02.1990	1	2	3	3	4	3	17.8	9.97	0.56	3h
13	Invention Certificate of the RF # 1806078A3, IPC 5 B 65 G 39/00, 30.03.1993	1	2	3	3	4	3	17.8	9.97	0.56	3h
14	Invention Certificate of the RF # 2121957C1, IPC 6 B 65 G 39/09, 20.11.1998	1						17.8	11.4	0.64	2low
15	Provisional patent of the RK # 7610, IPC B 65 G 39/00, published by IB # 6, 15.06.1999	2	4	5	5	4	4	17.8	16	0.90	1med
16	Provisional patent of the RK # 7756, IPC B 65 G 39/00, published by IB # 7, 15.07.1999	2	4	5	5	4	4	17.8	16	0.90	1med

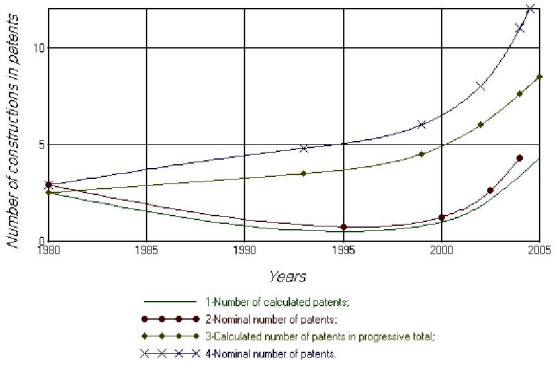

Figure 1. Patent information about roller supports with self-aligning bearing units (K5)

In order to develop morphologic classification of roller supports by design, invention certificates and patents have been used starting from 1929 and until present by developed countries of the world [3].

Technological level criterion, K_1, characterizes a new engineering design on trhe basis of obtained patents for roller supports in relation to existing

$$K_1 = (1-\psi) + r = 0{,}8r \text{ ,(5)}$$

where ψ is the parameter that corresponds to the level of recall factor $\psi = 0{,}2$; r is the invention recall factor for the designed roller.

Table 4. Roller support with self-aligning bearing units - K5

#	Initial data: Country, patent number, certificate of invention, class, subclass, date of publication	Number of designs in the patent	Base assessment i_1	i_2	i_3	i_4	i_5	q_{max}	q	recall factor r	Category of prediction
1	2	3	4	5	6	7	8	9	10	11	12
1	Invention Certificate of the USSR # 543561, IPC B 65 G 39/00 published 1970	1	1	4	4	4	4	17.8	11.3	0.63	2low
2	Invention Certificate of the USSR # 688392, IPC B 65 G 39/00 published 10.12.1979	3	2	3	5	5	4	17.8	12.5	0.7	2med
3	Invention Certificate of the RF # 1798274A1, IPC 5 B 65 G 39/00, 28.02.1993	1	1	4	4	4	4	17.8	11.4	0.64	2low
4	Invention Certificate of the RF # 1810241A1, IPC 5 B 65 G 39/00, published 23.04.1993	1	1	4	4	4	4	17.8	11.3	0.63	2low
5	Provisional patent of the RK # 7610, IPC B 65 G 39/00, published 15.06.1999	1	4	5	5	5	4	17.8	16.5	0.926	1med
6	Provisional patent of the RK # 13658, IPC B 65 G 17/24, published 14.11.2003	2	4	5	5	5	4	17.8	16.5	0.926	1med
7	Provisional patent of the RK # 17624, IPC B 65 G 17/00, published 13.06.2006	2	4	5	5	5	4	17.8	16.5	0.926	1med
8	Provisional patent of the RK # 1998, IPC B 65 G 15/00, published 26.06.2008	2	4	5	5	5	4	17.8	16.5	0.926	1med
9	Provisional patent of the RK # 20213, IPC B 65 G 47/52, published 25.06.2008	3	4	5	5	5	4	17.8	16.5	0.93	1med

Criterion of technical competitivity - K_2 characterizes the new patented engineering design in relation to existing objects made abroad

$$K_2 = (1-\psi) + r = 0.8 + r \text{ ,(6)}$$

In developed provisional patents (Table 4), Invention Recall Factor is $r = 0.9$, therefore, $K_1 + K_2 = 0.8 + 0.9 = 1.7$. From the point of view of engineering prediction, criteria of technological level and competitivity correspond to the top indicators.

Basing on morphological classification and GDT, patents are tested for the so-called "viability". The essence of information transformation is that patents and inventors' certificates are matched against GDT and for each characteristic an adequate position is found, then the score in points, also rates corresponding to these positions can be calculated.

Roller supports with self-aligning units in relation to the pole of the part - roller axis at the maximum load were used in inventions of the Moscow State Technical University n.a. N.E. Bauman and the State Design Institute "Soyuzprommehanizatsiya".

Roller supports with self-aligning bearing units are very promising, especially for transportation of heavy loads and when used in conveyors that operate in harsh conditions.

Table 5 below shows categories of patents for roller supports by the level of their viability.

Table 5. Categories of patents by the level of their viability

Semantic assessment of viability	Category of viability level	Roller support design K1	K2	K3	K4	K5	Total
Very promising	I	–	5	4	4	7	20
Promising	II	4	5	10	8	5	32
Little promising	III	9	10	14	6	–	39
Unpromising	IV	12	2	2	3	1	20

Examples of roller supports designs can be found in the documents mentioned in this article.

Discussion

1. The shown number of patents is usually less than nominal. Based on calculation of the above number of patents we can: identify prevailing technology area; find potentially possible proportions of introducing competing groups; and identify alternative technology areas.

2. Curves for the shown number of patents and the nominal number characterize the dynamics of generating new technical ideas.

3. With that, accrued curves of shown patents and their submission serve for defining generalized recall factor and characterize viability of this design.

4. On the basis of predictive assessment we see it is practicable to: identify patents in promising areas of machinery development; make decision about formulation of new research and development in order to create patent-clean domestic inventions.

Conclusions

1. Promising designs of roller supports have been shown. They cover patent search by world's developed countries since the 20-ties of the last century until present.

2. Basing on engineering prediction, a principle has been developed for increasing bearing capacity of roller supports for belt conveyors that operate in harsh conditions.

3. Use of ISO and FEM international standards in development of GDT make it possible to improve following design indicators: functional specifications, design, ergonomics, patent law, and indicators of reliability, unification and economical use of energy.

Corresponding Author:
Dr.Manezhanov Bolat Askerbekovich
Kazakh National University named after Satpayev
Satpayev Street, 22a, Almaty, 052213, Kazakhstan

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