CONTENTS

indexes selection, blocks of related SQL queries, SQL

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INDEXES SELECTION FOR BLOCKS OF RELATED SQL QUERIES

Abstract

This paper discusses the problem of minimizing the response time for a given database workload by a proper choice of indexes. The main objective of our contribution is to illustrate the database queries as a group and search for good indexes for the group instead of an individual query. We present queries block relation conditions for applying the concept of grouped queries index selection. In three experimental tests we provide measurements on the quality of the recommended approach.

1. INTRODUCTION

Getting database search result quickly is one of the crucial optimization problems in a relational database processing. The major strength of relational systems is their ease of use. Users interact with these systems in a natural way using nonprocedural languages that specify what data are required, but do not specify how to perform the operations to obtain those data [8]. Online Internet shops, analytics data processing or catalogue search are examples of structures where data search must be processed as quick as possible with minimal hardware resources involved. Common practice is to minimize the database search process at minimal cost. A database administrator (or a user) may redesign the physical hardware structure or reset the database engine parameters, or try to find suitable table indexes for a current query. Most vendors nowadays offer automated tools to adjust the physical design of a database as part of their products to reduce the DBMS's total cost of ownership [3]. As adding more CPUs or memory may not always be possible (i.e. limited budget) and maneuvering within hundreds of database parameter may lead to a temporary solution (wrong settings for other database queries), index optimization should be considered as being foremost.

Indexes are optional data structures built on tables. Indexes can improve data retrieval performance by providing a direct access method instead of the default

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full table scan retrieval method [7]. In the simple case, each query can be answered either without using any index, in a given answer time or with using one built index, reducing answer time by a gain specified for every index usable for a query [14]. Hundreds of consecutive database queries together with large amount of data involved lead to a very complex combinatorial optimization problem. Time needed to obtain result of both index-less tables joined together may be up to 45 minutes. Such delays are not acceptable for production environment processes. Indexes in such cases may reduce the response time of 50% (depending on which columns are used for the indexing). The classic index selection method focuses on a tree data structure, which could limit the search area as much as possible. Literature acknowledges us with such B-tree types as: (Known in the literature are those of the type of B-tree such as)

- Sorted counted B-trees, with the ability to look items up either by key or by number, could be useful in database-like algorithms for query planning [5],
- Balanced B*-tree that balances more neighboring internal nodes to keep the internal nodes more densely packed [12],
- Counted B-trees with each pointer within the tree and the number of nodes in the subtree below that pointer [19].

The B-tree and its variants have been widely used in recent years as a data structure for storing large files of information, especially on secondary storage devices [11]. The guaranteed small (average) search, insertion, and deletion time for these structures makes them quite appealing for database applications.

The topic of current interest in database design is the construction of databases that can be manipulated concurrently and correctly by several processes. In this paper, we discuss a simple variant of the B-tree (balanced B*-tree, proposed by Wedekind [20] especially well-suited for use in a concurrent database system [15].

While the selection of indexes structure have a very important role in the design of database applications, one should plan the indexes structure and number of indexes at the early stage of database development operation. In such situations more important is to ask a question "how to choose a set of indexes for the selected query sets?". It turns out that the proper selection of indexes can bring significant benefits for the database query execution time. Typical approaches found in the literature mainly focus on the search indexes only for single column or single query [16], [10], [9], [17], [4]. In this paper, an approach associated with the search query indexes for groups called blocks is presented.

In this case we will consider B-tree indexes. A B-tree index allows fast access to the records of a table whose attributes satisfy some equality or range conditions, and also enables sorted scans of the underlying table [18]. Also, we focus on databases with the same SQL queries repeated periodically. By doing so, we eliminate database queries' low selectivity factor where no good indexes could be found due to changing queries sets.

The rest of the paper is organized as follows: in section 2, we describe a problem statement. In section 3, we briefly present classic index selection approach together with simple examples that will illustrate the subject. In section 4, we demonstrate new method of grouped queries index selection and compare examples results with classic approach. Test and comparisons with commercial tools results are presented in section 5. Section 6 presents our conclusions and further works.

2. PROBLEM STATEMENT

Motivation for this work is to suggest an approach of multi-queried SQL block where sub-optimal or optimal solution is to be found that gives decision makers some leeway in their decisions. The main goal is to choose a subset of given indexes to be created in a database, so that the response time for a given database workload together with indexes used to process queries are minimal.

The index selection problem has been discussed in the literature. Several standard approaches have been formulated for the optimal single-query and multi-query index selection. Some past studies have developed rudimentary on-line tools for index selection in relational databases, but the idea has received little attention until recently. In the past year, on-line tuning came into the spotlight and more refined solution was proposed. Although these techniques provide interesting insights into the problem of selecting indexes on-line, they are not robust enough to be deployed in a real system [18]. The problem is known in a literature as Index Selection Problem (ISP) According to [8] it is NP-hard. Note that in practice the space limit in the ISP is soft, because databases usually grow, thus the space limit is specified in such way that a significant amount of storage space remains free [13].

In a real life scenario, for thousands database queries (Fig. 1) compromising hundreds of tables and thousands of columns, the search space is huge and grows exponentially with the size of the input workload.

Considered case of Index Selection Problem can be defined in following way. Given is a set of tables:

$$T = \{T_1, \dots, T_i, \dots, T_n\}, \tag{1}$$

described by a set of columns included in the tables:

$$K = \{k_{1,1}, \dots, k_{1,l(1)}, \dots, k_{i,j}, \dots, k_{n,1}, \dots, k_{n,l(n)}\}\ , \tag{2}$$

where: $k_{i,j}$ is a j-th column of table T_i.

Each column $k_{i,j}$ corresponds to set of values $V(k_{i,j})$ (tuples set) included in this column.

	SELECT COUNT	DAY/MONTH
1	2674	29/02
2	2566	01/03
3	2560	02/03
4	2374	28/02
5	2342	04/03
6	2234	03/03
7	1827	25/02
8	1814	26/02
9	1744	27/02
10	1716	05/03
11	1679	01/06
12	1663	15/06
13	1658	27/07
14	1658	09/05

Fig. 1. Example of number of database queries in a given day for a production data warehouse

For the set of tables T various queries Q_i can be formulated (in SQL these are SELECT queries). These queries are put against the specified set of columns $K_i^* \subseteq K$. The result of query Q_i is set as:

$$A_i \subseteq \prod_{k_{i,j} \in K_i^*} V(k_{i,j}) \,, \tag{3}$$

where: $\prod_{i=1}^{n} Y_i = Y_1 \times Y_2 \times \ldots \times Y_n$ is a cartesian product of sets $Y_1, \ldots, Y_n$.
For a given database DB it is taken into account that A_i is a result of following function:

$$A_i = Q_i(K_i^* \,, Op(DB)) \,, \tag{4}$$

where: K_i^* is a subset of used columns, $Op(DB)$ is set of operators available in database DB of which relation describing query Q_i is built.

The time associated with the determination of the set A_i is depended on the DB database used (search algorithms, indexes structures) and adopted set of indexes $J \subseteq \mathcal{P}(K^*)$ (where $\mathcal{P}(K^*)$ - is a power set of K_i^*). It is therefore assumed that the query execution time Q_i in given database DB, is determined by the function: $t(Q_i, J, DB)$. In short the value of execution time for query Q_i, data base DB and set of indexes J will be define as: $t_i(J)$.

In the context of the so-defined parameters, a typical problem associated with the ISP responds to the question:

What set of indexes $J \subseteq \mathcal{P}(K_i^*)$ minimizes the query Q_i execution time: $t_i(J) \rightarrow min$?

When a multi-component set of queries $Q = \{Q_1, \dots, Q_m\}$ is considered, question takes the form:

What set of indexes $J \subseteq \mathcal{P}(K^*)$ minimizes the queries block Q execution time: $\sum_{Q_i \in Q} t_i(J) \rightarrow min$?

3. CLASSIC INDEX SELECTION APPROACH

Classic index selection approach focuses on individual query and tries to find good index or indexes set for tables in a single query in a given block. Such approach does not take into consideration queries in a block as a whole. By doing so, a database user may expose database to create excess number of indexes which could be redundant or not used for more than one query in an examined block. This could also result in utilizing too much disk space and time needed for the indexes creation. Finding good index group for a large database queries' block was never an easy task to do and usually users and database administrators rely on their experience and good practice. In the commercial use one may find tools that support the index selection process, such as SQL Access Advisor (Fig. 2) [6], Toad, SQL Server Database Tuning Advisor [1].

Let us consider three examples where given is a group of three database queries $Q = \{Q_1, Q_2, Q_3\}$:

Q_1: *SELECT * FROM T_1, T_2 WHERE $k_{1,1}$ < $k_{2,2}$ AND $k_{1,3}$=[const],*
Q_2: *SELECT * FROM T_2, T_3 WHERE $k_{2,2}$ = $k_{3,2}$,*
Q_3: *SELECT * FROM T_2 WHERE $k_{2,1}$ > [const].*

Interpretation of this type of queries (according to (4)) is as following:
Q_1: searching for a set of triples: $A_i = \{(a, b, c): a \in V(k_{1,1}), b \in V(k_{2,2}), c \in V(k_{1,3}); a < b, c = [const]\}$,
set $K_1^* = \{k_{1,1}, k_{2,2}, k_{1,3}\}$.
Q_2: searching for a set of pairs: $A_i = \{(a, b): a \in V(k_{2,2}), b \in V(k_{3,2}); a = b\}$,
set $K_2^* = \{k_{2,2}, k_{3,2}\}$.
Q_3: searching for a set: $A_i = \{a: a \in V(k_{2,1}); a = [const]\}$,
set $K_3^* = \{k_{2,1}\}$.

Tables T_1, T_2, T_3 contain 1*10^6 records each. No indexes are built on either table: $J = \emptyset$. With the first test run, database returned following response times: $t_1(J) = 2040$s, $t_2(J) = 3611$s, $t_2(J) = 345$s respectively, resulting in full table scans for each Q. Queries Q ran on database Oracle 11.2.0.1 installed on server with Redhat 6 operating system with 64GB memory and ASM used for disk storage.

The classic approach requires treating every database query individually. Hence indexes are built: $k_{1,1}$ and $k_{1,3}$ on table T_1; $k_{2,1}$, $k_{2,2}$ on table T_2; $k_{3,2}$ on table T_3. This kind of indexes are represented by the set: $J = \left\{\{k_{1,1}, k_{1,3}\}, \{k_{2,2}\}, \{k_{3,2}\}, \{k_{2,1}\}\right\}$ containing four sets. Each element (set) of J contains the columns which are used to build the indexes. For example, the set $\{k_{1,1}, k_{1,3}\}$ means that we have to build one index for columns $k_{1,1}, k_{1,3}$.

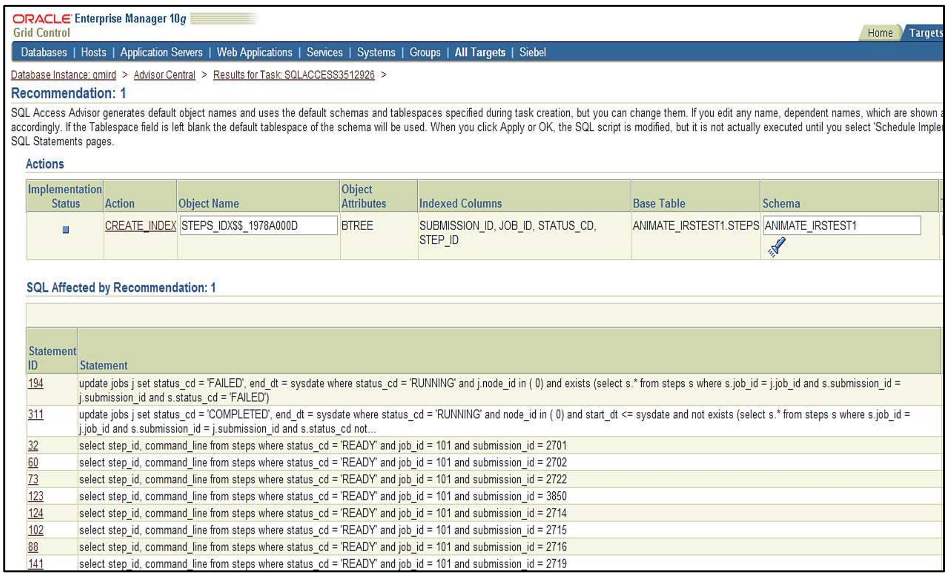

Fig. 2. Oracle's 10g2 SQL Access Advisor

The set of indexes J is built for three different tables, resulting in use of 2GB of additional disk space. With the second test run, database returned following response times: $t_1(J) = 2612$s, $t_2(J) = 2580$s, $t_3(J) = 5$s respectively. As the response time is better by approximately 10%, there is still unreasonable disk space used and time needed for creating 4 large indexes. Creating 4 indexes forced query optimizer to use them, and instead of decreasing Q_1 execution time, it got increased. This is because optimizer decided to read $k_{1,1}$ column index content first and because it couldn't find values for $k_{1,3}$ column, it performed full table scan for table T_1. Examples shows that selected indexes may increase the query execution performance where in other cases may have the opposite effect.

4. GROUPED QUERIES APPROACH

In this paper we focus on related queries group and because of this relation on the number of indexed columns. We take into account the search for a good index for the entire queries block. We propose a new approach by using multi-query SQL block selection. Such block consists tabular relations between queries, meaning that the number of tables columns used in previous query is present in other queries. The proposed approach could be an alternative to the classic index selection method, where one common index set can be found. Grouped queries approach has to be studied for its effectiveness and authenticity via a series of numerical tests. Furthermore, to compare the performance of the method we use commercial tools to compare results.

For previous examples, we suggest to create a pool of all columns taking part in all queries in a group and build sub-optimal indexes set for queried tables. Such task involves creating the weighted list that will include all the index candidate query-related columns and their number of occurrence in the examined queries block:

$$KW = \Big((k_{1,1}, 1\,), (k_{1,3}, 1), (k_{2,1}, 1), (k_{2,2}, 2), (k_{3,2}, 1) \Big). \qquad (5)$$

Of course, only $k_{2,2}$ column (marked by the box in (5)) is a query-related candidate column that could be used for the index creation. Nevertheless, other columns from remaining tables could also be revised. In that context, we suggest to create composite index for the same table T_2 on columns $k_{2,1}$ and $k_{2,2}$: $J = \Big\{ \{k_{2,1}, k_{2,2}\} \Big\}$. By doing so, user not only speeds up block execution but also saves significant volume of disk space. With the third test run, database returned following response times: $t_1(J) = 1235$s, $t_2(J) = 2430$s, $t_3(J) = 5$s, respectively, decreasing total execution time of 35% and saving disk space of 60%. This is due to the fact that only index is used or full table scan for non-indexed table resulting in smaller response times for Q_1 and Q_2. Database optimizer does not need to perform an additional read operation (separate for index and if values not found and separate for a table). This proves that indexes should be selected with care.

Determining the answers to a set of queries can be improved by creating some indexes.

Classic index selection focuses on each query individually and final indexes set is a sum of indexes sub-sets for each query.

We show that groups of queries, one can get better indexes set if such group is treated as a whole.

Grouped queries index search can only benefit and have an advantage over single query search, only if queries in the group satisfy the condition of mutual dependence. Queries Q_1, Q_2, Q_3, from previous examples are dependent so below statement applies. Such dependency must be clearly defined.

In the present case, the dependence set of queries Q is determined by connectivity of hypergraph $G(Q)$.

Example of a hypergraph for considered queries Q is presented on Fig. 3.

In this type of graph vertices represent the columns used in queries Q, edges connect those vertices which combined make table T_a(dashed line hyper edge) or related queries Q_i (solid line hyper edge). For example, hyper edge connecting vertices $k_{1,1}, k_{2,2}, k_{1,3}$ represents relation with query Q_1.

It is assumed that the query set $\boldsymbol{Q}$ is related if corresponding hypergraph $\boldsymbol{G(Q)}$ is consistent.

In this context, the group queries indexes set creation can benefit compared to classic index selection only for related sets.

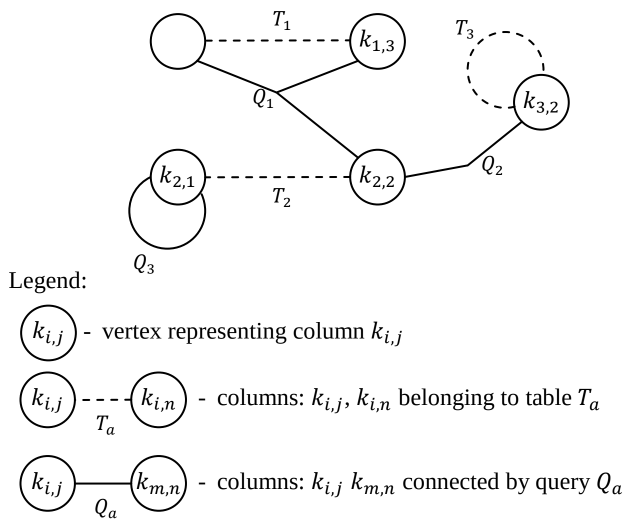

Fig. 3. Hypergraph for considered set of queries $\boldsymbol{Q}$

As a counterexample, given is a group of three database queries $Q^* = \{Q_1^*, Q_2^*, Q_3^*\}$:

Q_1^*: *SELECT * FROM* T_1, T_2 *WHERE* $k_{1,1}$ > $k_{1,2}$,
Q_2^*: *SELECT * FROM* T_2, T_3 *WHERE* $k_{2,1}$ = $k_{3,2}$,
Q_3^*: *SELECT * FROM* T_4 *WHERE* $k_{4,1}$ > *[const]*.

Example of a hypergraph for considered queries Q^* is presented on Fig. 4. This kind of hypergraph presented is inconsistent. For this reason queries Q^* are treated as the unrelated queries.

Unrelated queries for index selection process means they cannot be treated as a group. In such cases best index set is a set determined for each query individually:

$$J^* = \{\{k_{1,1}, k_{1,2}\}, \{k_{2,1}\}, \{k_{3,2}\}, \{k_{4,1}\}\}. \tag{6}$$

Weighted list for Q^* that that includes all the index candidate columns:

$$KW^* = ((k_{1,1}, 1), (k_{1,2}, 1), (k_{2,1}, 1), (k_{3,2}, 1), (k_{4,1}, 1)). \tag{7}$$

One can notice there are no query-related candidate columns (single column occurrence) that could be used for the grouped queries index set creation. Each table T_i will have to be indexed separately for each individual query Q^*.

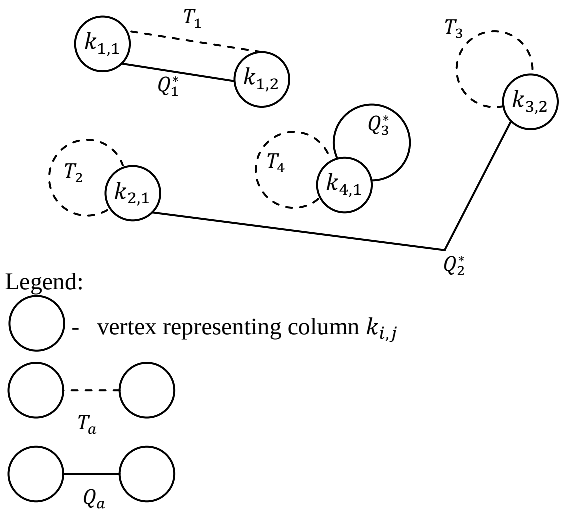

Fig. 4. Hypergraph for considered set of queries Q^*

5. EXPERIMENTAL TESTS

In the previous section we show two examples where grouped queries approach may be beneficial for SQL blocks with related queries, which is blocks of queries that can be graphically represented by a consistent hypergraph (see Fig. 3.).

In such context, a question needs to be asked: how does the efficiency of obtained indexes (calculated as a response time for a given query set) depend on the degree of density of these types of hypergraphs?

In order to answer this question we carry out 3 experiments that involve index selection for 3 different queries blocks with changing hypergraph density degree.

Each of the analyzed query blocks: Q^1, Q^2, Q^3 consists of three queries which characterize relations between columns of three database tables: $T = \{T_1, T_2, T_3\}$, containing 10×10^6 rows each.

For experimental purposes we use Oracle database, version 10.2.0.3 installed on server with Redhat 6 operating system with 64GB memory and ASM used for disk storage.

Each of the queries blocks Q^1, Q^2, Q^3 are presented (using the SQL language notation) in Tab. 1, Tab. 2, Tab. 3, respectively.

Database queries are constructed so that the corresponded hypergraph (presented in Fig. 5,6,7) has a varied density. It is assumed that the density ρ_i of a hypergraph describes common relations between queries of block Q^i and in example of a block with 3 queries, density is defined as follows:

$$\rho_i = \frac{\left|\left(K_{i,1}^* \cap K_{i,2}^* \cap K_{i,3}^*\right) \cup \left(K_{i,1}^* \cap K_{i,2}^*\right) \cup \left(K_{i,1}^* \cap K_{i,3}^*\right) \cup \left(K_{i,2}^* \cap K_{i,3}^*\right)\right|}{\left|K_{i,1}^* \cup K_{i,2}^* \cup K_{i,3}^*\right|}$$

, where: $\rho_i \in [0,1]$, $\rho_i = 0$ – describes no relations between queries in a block, and
$\rho_i = 1$ describes presence of each column in each query in a block.
$K_{i,j}^*$- is a subset of columns used in query Q_j^i

Density of a hypergraph is calculated as a proportion of number of common columns to number of all columns used in the block queries. Densities of analyzed blocks from this experiment are as follows:

- block Q^1 (Tab. 1): $\rho_1 = 0$
- block Q^2 (Tab. 2): $\rho_2 = \frac{8}{14} = 0{,}57$
- block Q^3 (Tab. 3): $\rho_3 = \frac{11}{12} = 0{,}91$

The presented values should be interpreted as follows: density of a hypergraph of queries block Q^1 is zero ($\rho_1 = 0$), meaning there are no relations between queries (no relations). In turn, density of a hypergraph of queries block Q^3 is $0{,}91$, meaning relation between queries are very strong (high relation – density is close to 1).
Each of the three experimental queries blocks is examined by three different tests so that a good index group for each query block is found:

1. index selection with use of advisory tools,
2. classic index selection approach,
3. grouped queries index selection approach

In the first test we use 2 different index selection advisory tools. One is the Oracle SQL Access Advisor, provided together with the server database installation package. Another is TOAD package, developed by Quest company. Oracle's software has ability to search for indexes not only for individual queries but also for a queries block (SQL Tuning Set).

TOAD tool treats every SQL query within a group as an individual and indexes are selected individually, too.

For 2 other tests (classic and grouped queries approach) we use our own index selection adaptive algorithm.

The results for all 3 tests we carry out are shown below:

Test 1: For queries blocks with recommendations of index selection advisory tools, each block execution times are as follows:

- for block Q^1 - 12s
- for block Q^2- 267s
- for block Q^3- 368s.

Test 2: For queries blocks with recommendations of classic index selection approach, each block execution times are as follows:

- for block Q^1- 3s
- for block Q^2- 253s
- for block Q^3- 320s.

Test 3: For queries blocks with recommendations of grouped queries index selection approach, each block execution times are as follows:

- for block Q^1- 3s
- for block Q^2 - 245s
- for block Q^3 - 289s.

Based on the above results, differences between advisory tools, classic and grouped queries approach for blocks execution times are calculated as follows:

- 0s for queries block with no relations (block Q^1).
- 8s (3%) for queries block with low relations (block Q^2).
- 31s (9.5%) for queries block with high relations (block Q^3).

The obtained results show that together with the increase in queries' relations (ρ_i density increase), the efficiency of the grouped queries approach against classic index selection approach also increases. We don't notice efficiency increase for queries block with no relation (block Q^1). Furthermore, for this block indexes developed from classical approach are identical to those with grouped queries index selection method (see Tab. 1).

It is worth noting that the commercial advisory tools seem to be useful only for non-related block queries Q^1 ($\rho_1 = 0$). For other queries blocks (Q^2, Q^3) advisors are unable to recommend any indexes whatsoever (see Tab. 2, Tab. 3). As it seems, with block queries density increase the effectiveness of such tools decrease.

Tab. 1. Database queries Q^1 with no relations ($\rho_1 = 0$) and indexes recommendations

<table>
<tr>
<td rowspan="3">Database queries set with no relations:

QQ_1: SELECT T1_2.KOL4, T1_1.KOL5
FROM TEST1 T1_1,
(SELECT KOL3, KOL4 FROM TEST1) T1_2
WHERE T1_1.KOL1 BETWEEN T1_1.KOL2 AND T1_2.KOL4
AND T1_2.KOL3 = 1234
GROUP BY T1_2.KOL4, T1_1.KOL5;

Q_2: SELECT TEST2.KOL1, TEST2.KOL4
FROM TEST2 WHERE TEST2.KOL4 > 100
AND TEST2.KOL1 < 100 AND TEST2.KOL3 >ANY
(SELECT TEST2.KOL3 FROM TEST2 WHERE TEST2.KOL2 < 100)
GROUP BY TEST2.KOL1, TEST2.KOL4 ORDER BY 2;

Q_3: SELECT KOL2, KOL4 FROM TEST3 WHERE KOL4 < 1000
AND KOL1 IN (0,5,10)
UNION ALL
SELECT KOL2, KOL5 FROM TEST3 WHERE KOL2 > 1000
AND KOL5 IN (1,10,100);</td>
<td>Oracle SQL Advisor + TOAD suggestiosn:
CREATE INDEX k1_col3_col4_idx ON $T_1(k_{1,3}, k_{1,4})$;
CREATE INDEX k2_col1_col3_idx ON $T_2(k_{2,1}, k_{2,3})$;
CREATE INDEX k2_col2_col3_idx ON $T_2(k_{2,2}, k_{2,3})$;
CREATE INDEX k3_col1_col2_col4_idx ON $T_3(k_{3,1}, k_{3,2}, k_{3,4})$;
CREATE INDEX k3_col2_col5_idx ON $T_3(k_{3,2}, k_{3,5})$;</td>
</tr>
<tr>
<td>Classic index selection approach:
CREATE INDEX k1_col3_idx ON $T_1(k_{1,3})$;
CREATE INDEX k2_col1_col2_col4_idx ON $T_2(k_{2,1}, k_{2,2}, k_{2,4})$;
CREATE INDEX k2_col2_idx ON $T_2(k_{2,2})$;
CREATE INDEX k3_col1_col4_idx ON $T_3(k_{3,1}, k_{3,4})$;
CREATE INDEX k3_col5_idx ON $T_3(k_{3,5})$;</td>
</tr>
<tr>
<td>Grouped queries approach:
CREATE INDEX k1_col3_idx ON $T_1(k_{1,3})$;
CREATE INDEX k2_col1_col2_col4_idx ON $T_2(k_{2,1}, k_{2,2}, k_{2,4})$;
CREATE INDEX k2_col2_idx ON $T_2(k_{2,2})$;
CREATE INDEX k3_col1_col4_idx ON $T_3(k_{3,1}, k_{3,4})$;
CREATE INDEX k3_col5_idx ON $T_3(k_{3,5})$;</td>
</tr>
</table>

Tab. 2. Database queries Q^2 for low relations ($\rho_2 = 57$) and indexes recommendations

Database queries set with low relations:	Oracle SQL Advisor + TOAD suggestion:
Q_1: SELECT T3.KOL1,T3.KOL2 FROM TEST1 T1, (SELECT T2.KOL3, T2.KOL5 FROM TEST2 T2, TEST1 T1 WHERE T2.KOL3=T1.KOL5) T2, TEST3 T3 WHERE T1.KOL5 = T3.KOL4 AND T3.KOL1 = T2.KOL3 AND T3.KOL5 = ANY (SELECT T2.KOL5 FROM TEST2 T2, TEST1 T1 WHERE T2.KOL4=T1.KOL3) ORDER BY 1,2; Q_2: SELECT DISTINCT T1.KOL , T1.KOL2 , COUNT(*) FROM TEST1 T1, TEST3 T3, (SELECT T2.KOL4, T2.KOL1 FROM TEST2 T2, TEST3 T3 WHERE T2.KOL3=T3.KOL5) T2 WHERE T1.KOL1 = T2.KOL1 AND T2.KOL4 = T3.KOL4 GROUP BY T1.KOL1, T1.KOL2 ORDER BY 1 DESC; Q_3: SELECT DISTINCT T1.KOL2, T2.KOL5, COUNT(2) FROM TEST2 T2, TEST1 T1, TEST3 T3 WHERE T1.KOL4 = T3.KOL4 AND T1.KOL1 = T2.KOL3 AND T1.KOL5 > ANY (SELECT T2.KOL5 FROM TEST2 T2 WHERE T2.KOL1=1000) AND (T3.KOL3 > T2.KOL3) GROUP BY T1.KOL2, T2.KOL5 ORDER BY 1,2 DESC;	NO INDEXES *Classic index selection approach:* CREATE INDEX k1_col1_col2_idx ON $T_1(k_{1,1}, k_{1,2})$; CREATE INDEX k1_col5_idx ON $T_1(k_{1,5})$; CREATE INDEX k2_col1_col3_idx ON $T_2(k_{2,1}, k_{2,3})$; CREATE INDEX k2_col3_col4_idx ON $T_2(k_{2,3}, k_{2,4})$; CREATE INDEX k2_col4_idx ON $T_2(k_{2,4})$; CREATE INDEX k3_col1_idx ON $T_3(k_{3,1})$; CREATE INDEX k3_col3_idx ON $T_3(k_{3,3})$; CREATE INDEX k3_col4_idx ON $T_3(k_{3,4})$; *Grouped queries approach:* CREATE INDEX k1_col1_idx ON $T_1(k_{1,1})$; CREATE INDEX k2_col1_col3_col4_idx ON $T_2(k_{2,1}, k_{2,3}, k_{2,4})$; CREATE INDEX k3_col2_col4_idx ON $T_3(k_{3,2}, k_{3,4})$;

Tab. 3. Database queries Q^3 with high relations ($\rho_3 = 0,91$) and indexes recommendations

Database queries set with high relations:	Oracle SQL Advisor suggestion + TOAD suggestion:
Q_1: SELECT COUNT(*) FROM TEST1 INNER JOIN TEST2 ON TEST1.KOL1 = TEST2.KOL2 AND TEST1.KOL2 = TEST2.KOL3 AND TEST1.KOL3 = TEST2.KOL4 INNER JOIN TEST3 ON TEST2.KOL2 = TEST3.KOL1 AND TEST2.KOL4 = TEST3.KOL3 AND TEST2.KOL5 = TEST1.KOL3; Q_2: SELECT COUNT(*) FROM TEST1 INNER JOIN TEST2 ON TEST1.KOL1 = TEST2.KOL1 AND TEST1.KOL3 = TEST2.KOL3 AND TEST1.KOL2 = TEST2.KOL4 AND TEST2.KOL2 = TEST1.KOL2 INNER JOIN TEST3 ON TEST2.KOL1 = TEST3.KOL1 AND TEST2.KOL2 = TEST3.KOL2 AND TEST2.KOL3 = TEST3.KOL3 AND TEST2.KOL5 = TEST3.KOL5; Q_3: SELECT COUNT(*) FROM TEST1 INNER JOIN TEST2 ON TEST1.KOL1 = TEST2.KOL5 AND TEST2.KOL3 = TEST1.KOL3 INNER JOIN TEST3 ON TEST2.KOL5 = TEST3.KOL1 AND TEST2.KOL1 = TEST3.KOL5 AND TEST3.KOL3 = TEST2.KOL3 AND TEST1.KOL2 = TEST3.KOL5;	NO INDEXES *Classic index selection approach:* CREATE INDEX k1_col1_col3_idx ON $T_1(k_{1,1}, k_{1,3})$; CREATE INDEX k1_col2_idx ON $T_1(k_{1,2})$; CREATE INDEX k2_col1_col2_idx ON $T_2(k_{2,1}, k_{2,2})$; CREATE INDEX k2_col3_col5_idx ON $T_2(k_{2,3}, k_{2,5})$; CREATE INDEX k2_col4_idx ON $T_2(k_{2,4})$; CREATE INDEX k3_col1_idx ON $T_3(k_{3,1})$; CREATE INDEX k3_col3_idx ON $T_3(k_{3,3})$; CREATE INDEX k3_col5_idx ON $T_3(k_{3,5})$; *Grouped queries approach:* CREATE INDEX k1_col1_col2_col3_idx ON $T_1(k_{1,1}, k_{1,2}, k_{1,3})$; CREATE INDEX k3_col1_col3_col5_idx ON $T_3(k_{3,1}, k_{3,3}, k_{3,5})$;

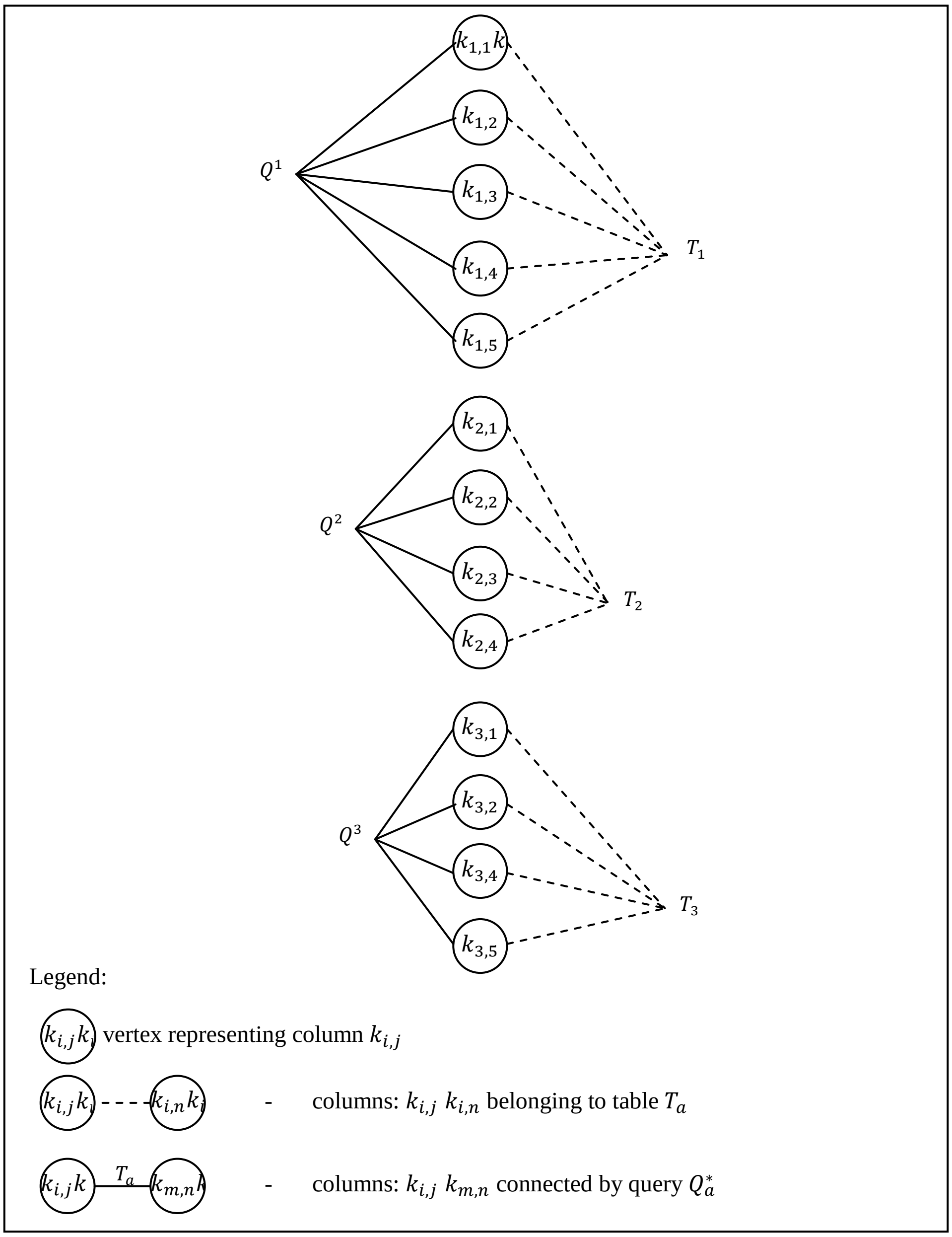

Fig. 5. Hypergraph for example set of queries Q^1 with no relations: $\rho_1 = 0$

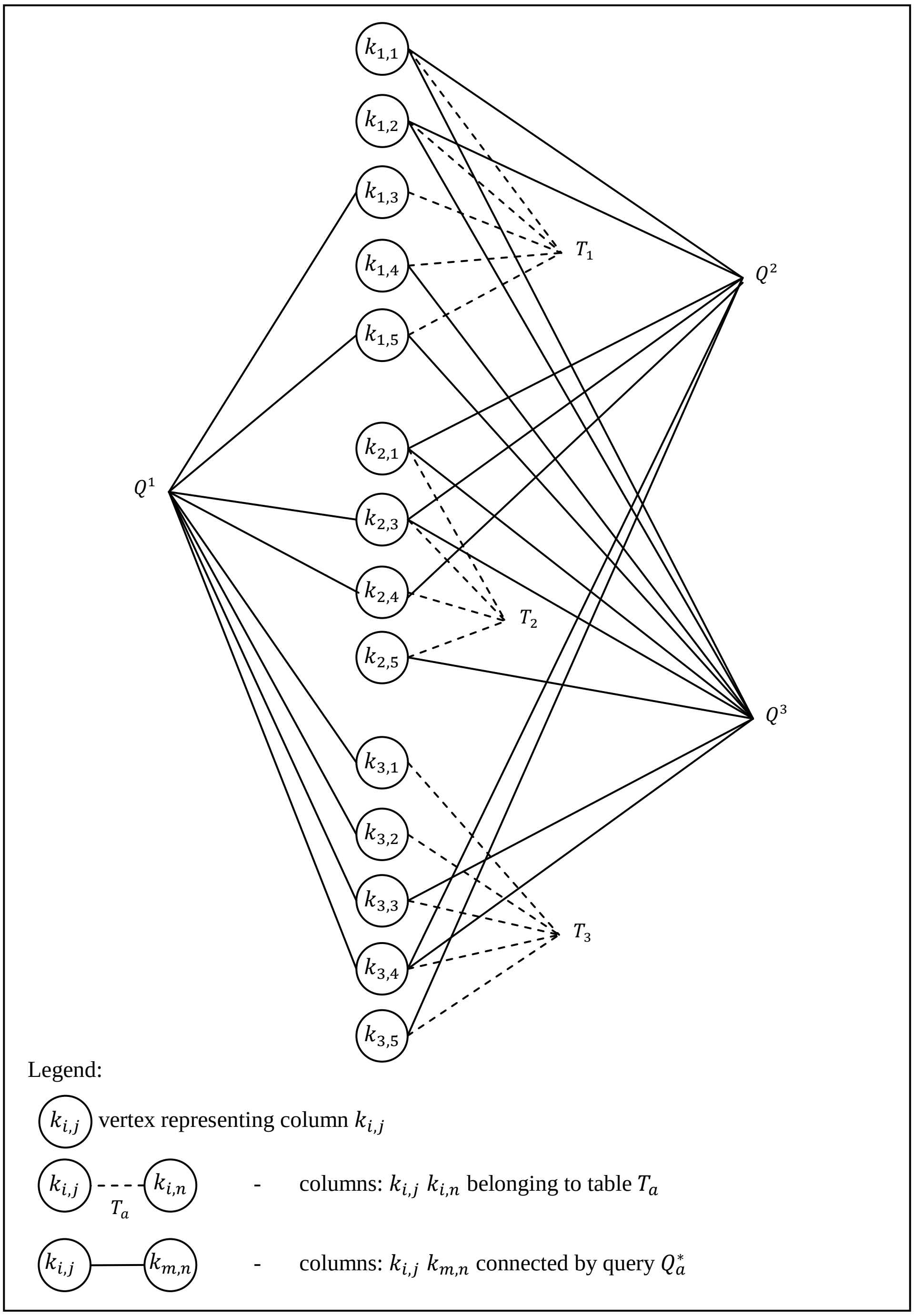

Fig. 6. Hypergraph for set of queries Q^2 with low relations: $\rho_2 = 0,57$

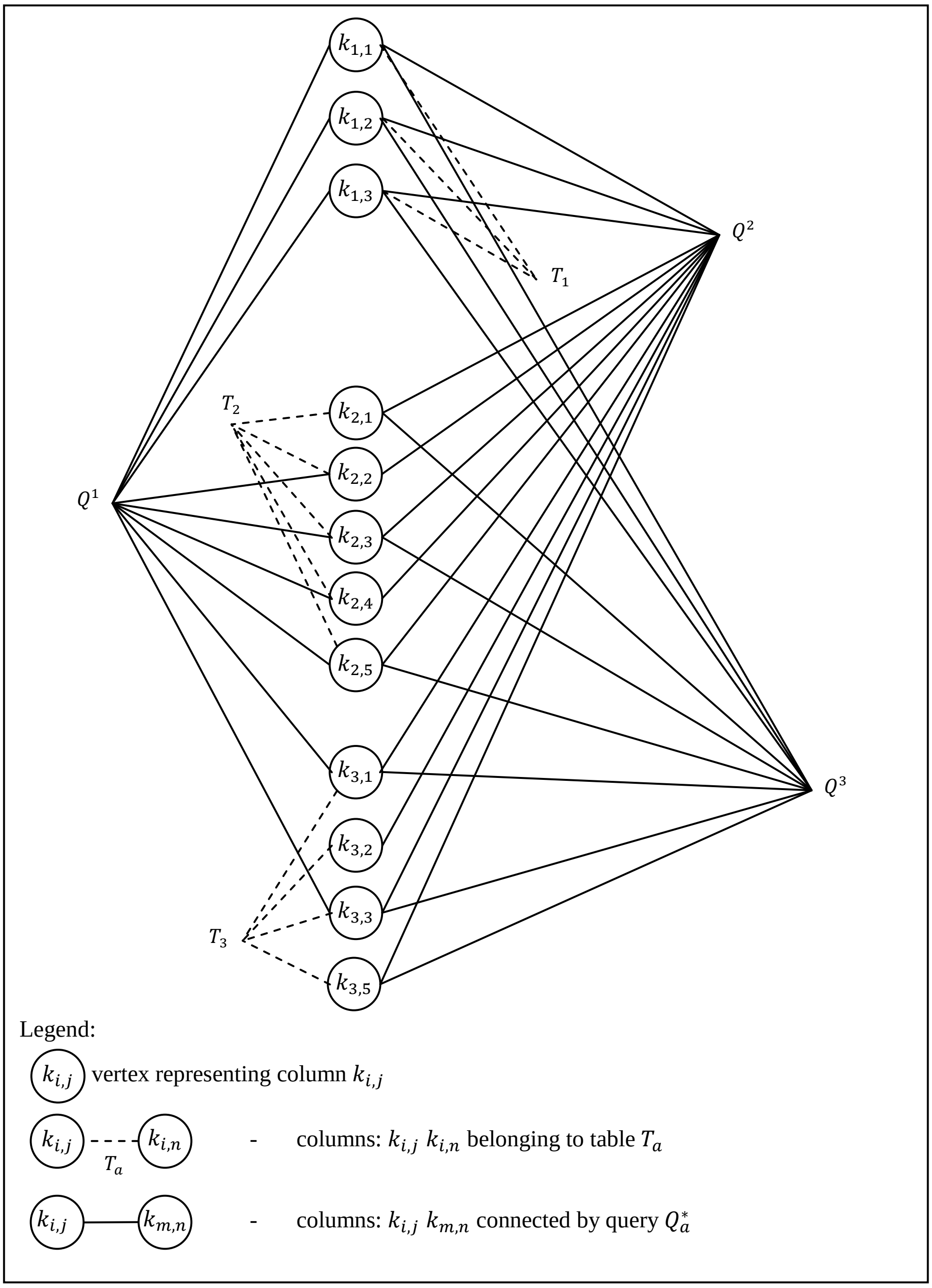

Fig. 7. Hypergraph for set of queries Q^3 with concentrated relations: $\rho_3 = 0,91$

6. CONCLUSIONS

Finding a good index or indexes set for a table is very important for every relational database processing not only from the performance point but also cost aspect. Indexes can be crucial for a relational database to process queries with reasonable efficiency, but the selection of the best indexes is very difficult.

Presented examples show that there is a need for finding an automatic index selection mechanism with grouped queries-oriented rather than a classic (single query) approach for blocks with related queries. Practice shows that index focus on grouped queries gives better results and enables user to save time needed for index creation. It also saves system hardware resources. In the examples we show grouped queries indexes set are more effective than individual queries indexes because queries Q^2, Q^3 satisfy the relation condition (see Tab. 2,3). For blocks with no related queries we show grouped queries indexes set are not more effective than individual queries indexes because queries Q^1 do not satisfy the relation condition (see Tab. 1).

One should note that the experiments we carry out are to determine index sets that minimize queries blocks execution time only. What is important in the general case are different parameters such as: index creation cost, number of indexes and disk storage allocation. Future research will take into account the resources needed to create an index and storage resources.

For the automatic index selection, the system continuously monitors queries block and gathers information on columns used in queries. The administrator (or user) can summon the automatic system at any time to be presented with the current index recommendation, or tune it to the queries block needs. The system also presents the user index set and allows user to choose best option. User decides whether to reject or accept proposed set. Due to index interactions, the user's decisions might affect other indexes in the configuration, so the recommendation would need to be regenerated, taking the user's constraints into account.

In the presented examples we show three situations of database queries block execution, one without indexes, one with classic separate queries indexing and one with grouped queries indexing. Examples showed that one should create grouped indexes only for related queries. In that context presented relationship may be treated as sufficient condition for the evaluation of grouped queries indexing.

Our current works are focused on grouped queries index selection method with the use of genetic algorithm [2] that analyzes database queries, suggests indexes' structure and tracks indexes influence on the queries' execution time. We work on the system that will be used in an attempt to find better indexes for a critical part of long-running database queries in testing and production database environment. Recording queries with good indexes together with their total execution time is a starting point for broader searches in the future. Simple test presented in this article proves effectiveness of this method. The developed system is scalable: there is a potentiality of combining smaller queries' blocks into larger series and finding better solution based on execution history.

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packaging machine design, variability, family of packages

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ANALISYS OF VARIABILITY OF THE FAMILY OF PACKAGES AND THE VERSATILE PACKAGING MACHINE DESIGN

Abstract

The article provides design and engineering analysis of groups of packages. The relationship between the functional units of packaging machines and related groups designs packages is traced. The method for calculation of the versatility rate of the packaging machine depending on its structure is offered.

1. INTRODUCTION

The rapid development of science and technology constantly stimulates production. That leads to satiation of the global food market with new products. Product life cycle is getting shorter, and the range of products expands increasingly [1]. As a result, the number of design types of packages increases generating the process of complication of packaging equipment and enhance of its functionality.

In view of considerable diversity of tare and the active development of mechanisms design the practical creating of versatile packaging machines can often be quite a challenge. Application of the described sequence of design is conducted on the example of polyfunctional machines for packing powders in polymeric packages. Such a machine generally consists of a block of functional modules-dispensers for measuring a given dose, a functional module (FM) unit for forming a polymer film package and it's sealing after filling with the metered dose and various auxiliary FM.

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2. DESIGN ANALYSIS OF PACKAGES

Evaluation of variability of products is carried out using the mathematical model, the general principles of which is hierarchical decomposition of products on the structural components – elements [2]. Each structural element is characterized by form, design and technological parameters. The elementary transformation of its forming is put in correspondence to each structural element. In turn, each such transformation can be realized with a set of FM. This leads to a complex optimization problem of synthesis of packaging machines with a large number of FM.

A polymeric package can be divided into its component parts: body; top and bottom; top, bottom, longitudinal and angular seams; special items (Fig. 1). Each item can be presented as a set of its variants

$$E_i = \{e_1, e_2, e_3, ..., e_y\} \tag{1}$$

where: e_y - any variant of constructive element.

The set E of all structural elements included in the family may be represented as the matrix of $x \times y$, x – being the quantity of diverse elements of the package:

$$E = \{E_1 \cup E_2 \cup E_3 \cup ... \cup E_x\} \tag{2}$$

$$E = \begin{pmatrix} e_{11} & ... & e_{1y} \\ ... & & ... \\ e_{x1} & ... & e_{xy} \end{pmatrix} \tag{3}$$

Repeatability of the items in a separate product design is characterized with the structural repeatability rate:

$$U = \frac{\Pi_i}{n_\Pi} \tag{4}$$

and a variety of structural elements in the product with respect to all possible designs – the variety rate:

$$V = \frac{\Pi_i}{E} \tag{5}$$

Thus, the generalized coefficient of variability of product family can be defined as the product of averages of the repeatability and variety rates:

$$K_{\text{var}} = \left(\frac{1}{E} \sum^{E} \frac{\Pi_i}{n_\Pi} \right) \cdot \left(\frac{1}{E} \sum^{E} \frac{\Pi_i}{E} \right) = \bar{U} \cdot \bar{V} \tag{6}$$

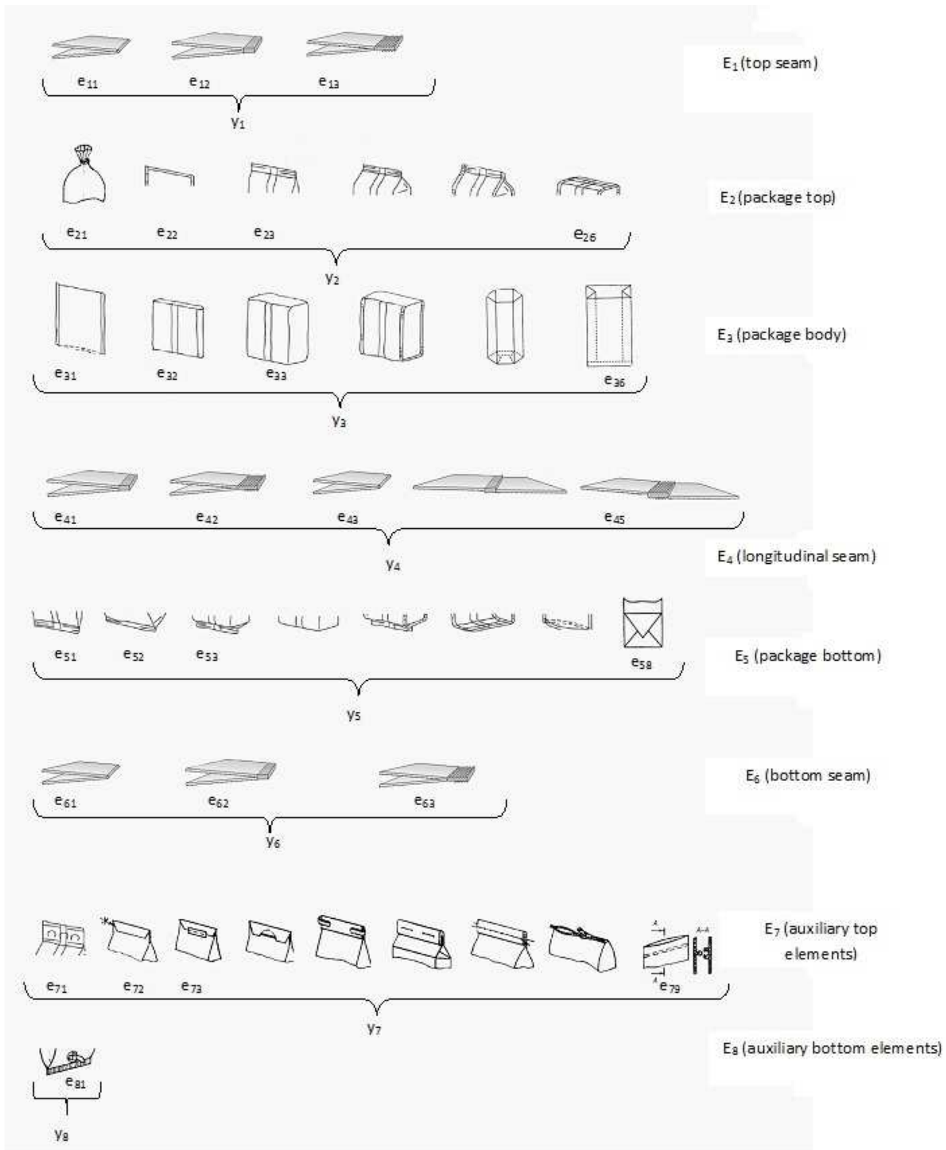

Fig. 1. Family of the elements of package

3. CALCULATION OF VERSATILITY FOR TECHNOLOGICAL MACHINES WITH DIFFERENT STRUCTURES

Assume that each FM successively forms the product specific element from a given set of possible sizes.

The total number of products that a packing machine may produce is determined depending on its structure (Fig. 2) and a set of design elements that any FM makes.

For a machine that consists of several sequential working FM the total number of products is defined as the product of the sets of design elements that each of FM can produce:

$$N_{П}^{ФМ} = \prod_{i=1}^{x} E_i^{ФМ} \tag{7}$$

where: $E_i^{ФМ}$ – number of options for the design elements of a product that the i-th FM produces.

Under the serial connection is to be understood a combination of FMs, that can ensure the formation of each element of package at a time, and each subsequent modifying a pretreated product and each finished product must undergo processing by all the FMs.

In case when the FM can perform an unlimited number of variants of package elements the versatility factor for it equals to one. But actually this FM does not affect the versatility of the entire machine because those variants of transformations it carries out are be constrained the other FM (e.g. pulling mechanism can move the film on any length, but move step will be determined by the capacity and capabilities of the dispenser and seaming mechanisms). Therefore, the characteristics of such FM can not be taken into account in the calculation of the versatility.

Then the factor of versatility for serial connection the FM is:

$$K_{У}^{srl} = 1 - \frac{1}{E_1^{ФМ} \cdot E_2^{ФМ} \cdot \ldots \cdot E_x^{ФМ}} = 1 - \frac{1}{N_{П}^{ФМ}} = 1 - \frac{1}{\frac{1}{1-K_{У1}} \cdot \frac{1}{1-K_{У2}} \cdot \ldots \cdot \frac{1}{1-K_{Уx}}} = 1 - \prod_{i=1}^{x}(1-K_{Уi}) \tag{8}$$

In real conditions of some of the FM do not provide the necessary elements of product formation [3]. As a consequence, there are impossible combinations of operations in the process. The versatility losses in each FM will amount.

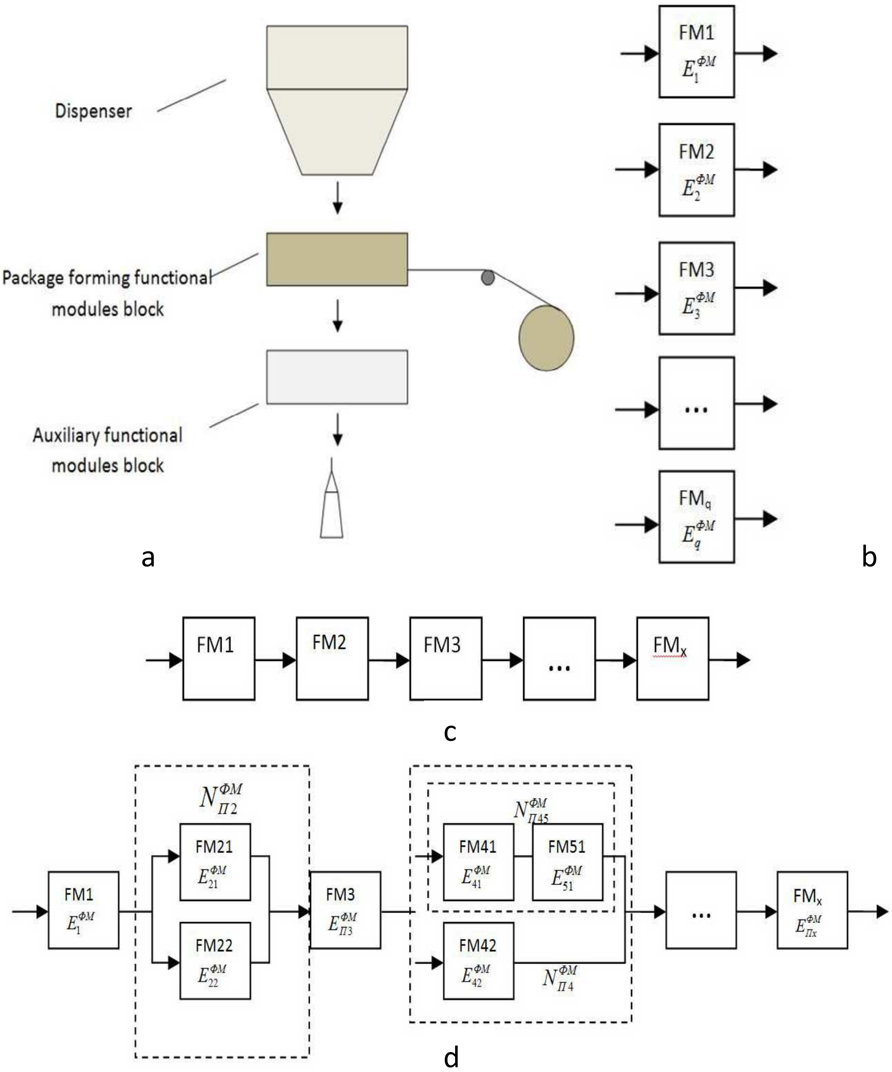

Fig. 2. General structure of the packaging machine (a) and the schemes of the parallel (b), serial (c) and mixed (d) connection of FMs

$$\xi = 1 - \frac{E_i^{\Phi M}}{E_i} \tag{9}$$

For packaging machine, that consists of serial-connected FM's:

$$\Xi^{srl} = \prod_{i=1}^{x} (1 - \frac{E_i}{E_i^{\Phi M}}) = \prod_{i=1}^{x} \xi_i \tag{10}$$

Parallel connection of modules allows the realization of functions at a certain time only one of them. In this case, the number of products that q parallel-connected FM can produce is determined by the sum of sizes for each of them

$$N^{\Phi M} = \sum_{i=1}^{q} E_i^{\Phi M} \tag{11}$$

The situations may occur when one or more modules can form the same elements. Then at any time a bunch of parallel-connected modules produces

$$N^{\Phi M} = \bigcup_{i=1}^{q} E_i^{\Phi M} = \sum_{j=1}^{q} \Pi_j \tag{12}$$

types of products. Expanding functionality in this case is achieved by unique variants Π_j of structural elements of the product, that each of FM makes. Thus, with the addition of each new module the versatility loss reduces:

$$\Xi^{prl} = 1 - \sum_{i=1}^{q} (1 - \frac{E_i}{E_i^{\Phi M}}) = 1 - \sum_{i=1}^{q} \xi_i \tag{13}$$

For parallel connection FM the coefficient of versatility is determined according to the following dependence:

$$K_y^{prl} = 1 - \frac{1}{\sum_{j=1}^{q} \Pi_j} = 1 - \frac{1}{1 - \sum_{j=1}^{q} (\frac{1}{1 - K_{yq}})} \tag{14}$$

Mixed FM connection is a combination of serial and parallel. Thus arbitrarily complex machine is reduced to a chain of serial-connected parts. Several FM, which operate in parallel or sequentially on the same level are considered as one group.

For any machine the number of types and sizes of finished products and versatility coefficient can be calculated by the following dependencies:

$$N^{\Phi M} = \prod_{i=1}^{\alpha} E_i^{\Phi M} \cdot \prod_{i=1}^{\beta} \sum_{j=1}^{q} \Pi_j \tag{15}$$

$$K_y = 1 - \frac{1}{N^{\Phi M}} = 1 - (K_{yi}^{srl} \cdot K_{yi}^{prl}) = 1 - (\prod_{i=1}^{\alpha} (1 - K_{yi}) \cdot \prod_{i=1}^{\beta} \frac{1}{\sum_{j=1}^{q} (\frac{1}{1 - K_{yq}})}) \tag{16}$$

where: α and β – number of series-connected FM and FM parallel connection, respectively.

The loss of versatility for mixed connection of FM:

$$\Xi = \Xi^{srl} \cdot \prod^{\beta} \Xi^{prl} = \prod_{i=1}^{\alpha} \xi_i \cdot \prod_{i=1}^{\beta} (1 - \sum_{j=1}^{q} \xi_j) \tag{17}$$

.

Therefore

$$[N] = N^{\Phi M} \cdot \Xi \tag{18}$$

.

Since always Ξ <1, the quantity of types and sizes of packages produced by packaging machine is less than their number in the family:

$$[N] > N^{\Phi M} \tag{19}$$

4. CORRESPONDENCES BETWEEN PRODUCT AND FM DESIGNS

The transition from a family of packages to the structure of packaging machine, occurs due to synthesis of the machine workflow from elementary operations by establishing correspondence between the elements of package design, FM realizing them. This raises some difficulties since the same structural element of package can be formed by various elementary operations, and each of the elementary operations – can be performed by different in design FM. Then for each design package the set of elementary operations is defined, and each elementary technological operation (ETO) is determined by the set of FM designs for its implementation

$$O_i = \{m_1, m_2, m_3, ..., m_y\} \qquad (20)$$

where: m_y – any variant is a working body.

For example, the longitudinal seam can be obtained as a result of continuous or discrete heating and compression of film layers with rollers or sponges of various designs. And vice versa - as a result of a basic technological operation depending on the design of FM the family of elements can be identified. In this connection it is necessary to further describe not only the type of structural element, but also a way of its formation. Therefore, during the design process will have two aspects to describe versatile packaging machine:

- Functional description which is the set of simple functions, the implementation of which ensures the formation of structural elements of package (EB) and set of connections between them defining the principles of operation of the packaging machine;
- Structural description which is the set of functional modules that create the layout of packaging machine, variants of their design (KB), and relations between them.

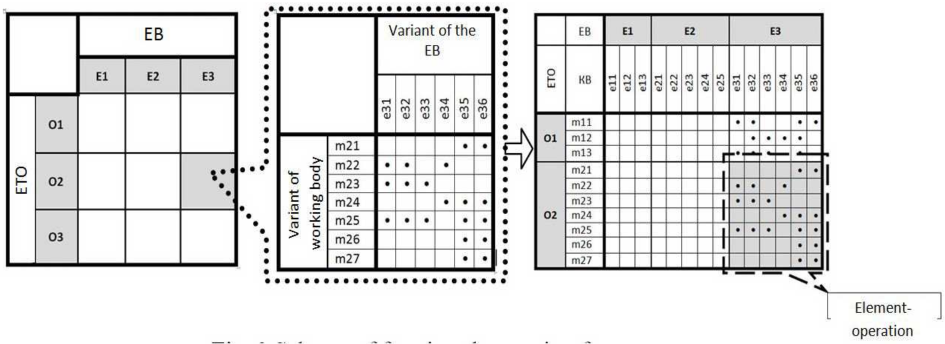

Fig. 3. Scheme of forming the matrix of structures.

The connections between the components and design FM look like "constructive element - version implementation - process operation - options of the construction". This correspondence is presented with Boolean matrix of structures. Generating of this matrix is based on the set of FM - the fundamental elements of the design of packaging machine used for formation of the corresponding structural elements of the package and ensuring the implementation of auxiliary functions. The work of a machine is considered as a set of ETO. Thus each ETO is associated with a structural element of the package - thereby defining the element-operation.

After the distinguishing of element-operations, the analysis of need of their implementation for each type of package and creating generalized technological operation of package forming is conducted. The generalized process operation should ensure the formation of structural elements inherent in all types of package in a specified sequence and implementation of support functions. It should also take into account the possibility of overlapping or simultaneous execution of functions. The given summary technological operation covers all possible ETO undertaken during formation package with all structural elements. In fact, it represents the array of designs FM and corresponding elements of the package, i.e. an array of element-operations (Fig. 3).

Transition to the technical description is the most difficult stage. The reason is that the range of elements package meets a wide range of technical functions of package-forming equipment. Given that there is a possibility of providing several functions or simultaneous formation of a family of the package elements decomposition of ETO into multiple simple functions for the relevant technological transformations is carried out. The decomposition is performed until the choice of technical means for each of them becomes apparent, and is provided by the only design of the working body. The result of such a function is the creation or modification of the corresponding version of package constructive element.

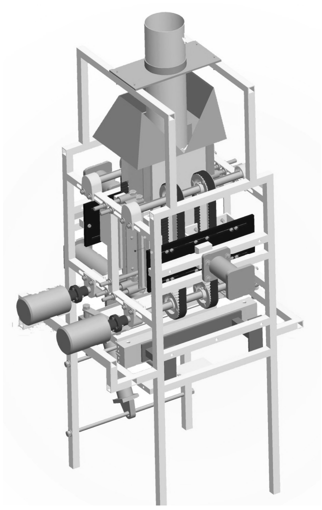

Fig. 4. 3D model of the designed versatile packaging machine

Spatially the FMs are placed in the order of transitions of the generalized technological operation. Changing the type of package is carried out by turning on or off the mechanisms that form the corresponding components. This completes the goal the versatile packing machine is to achieve - providing the implementation of all functions of package formation.

Basing on the described methodology the versatile packaging module was developed (Fig. 4). It is designed for packing granular products in polymeric packages 15 types with cross-sectional dimension of 90x160mm and seams up to 20mm [4]. The module consists of the following main components and mechanisms:

- mechanism forming a sleeve of film and providing product supply channel;
- pulling mechanisms;
- mechanisms for longitudinal seaming;
- devices formation of lateral folds;
- mechanism for transverse seaming, folding the bottom and cutting-off the finished package;
- mechanism for folding the bottom seam;
- frame.

The drive of mechanisms for longitudinal and transverse seaming and folding bottom is pneumatic while for pulling mechanisms - from the servomotor.

5. CONCLUSIONS

One of the promising directions of improving the efficiency of packaging industry is intensification of use of flexible manufacturing cells based on packaging machines. Important in this case is to ensure the versatility of the machines. Increased versatility can be achieved by using multifunctional machine elements as well as by the inclusion of mechanisms that perform new functions into the structure. In any case, the way the combination of elements in the machine should be taken into account.

The method of structural synthesis of versatile packing machines by selecting the order of the combination of technological operations and technical means for their ensuring based on the research of package design is illustrated by the example of the universal unit of functional modules for packaging granular products into plastic bags.

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advertising company, billboard, customer relationship management, cloud computing, software as a service,

Radosław URBAŃSKI[*]

LOCAL CRM APPLICATION FOR BILLBOARD ADVERTISING COMPANY

Abstract

The article presents development process of dedicated application that supports Customer Relationship Management. The software receiver is a small advertising company, whose main service is renting billboards. Implementation of CRM system inclines to further expansion of the application Transfer of implemented system into area of Cloud Computing is considered.

1. INTRODUCTION

Technological progress forces searching for solutions that improve company's functioning as well as its customer service. Available applications aren't often sufficient for enterprises which work in personal, individual business processes. This situation causes development of IT systems dedicated to specific requirements.

The subject analyzed here is a small advertising company, whose main service is renting billboards. Marketing Department and company executives get contractors. Negotiations proceed in the office of the firm or in the headquarters of their trade partner. Preliminary agreements and advertisement booking are made at meetings. Booking has a form of A4 paper sheet (Figure 1) with table that contains billboards description, booking months and prices. This reservation system isn't perfect. It occasionally happens that no one has time to copy booking sheet and a marketing or management employee takes it away, which causes the loss of important data. There are situations when there is a need to get remote information about actual reservation status, but no one can make that accessible (for example office is closed).

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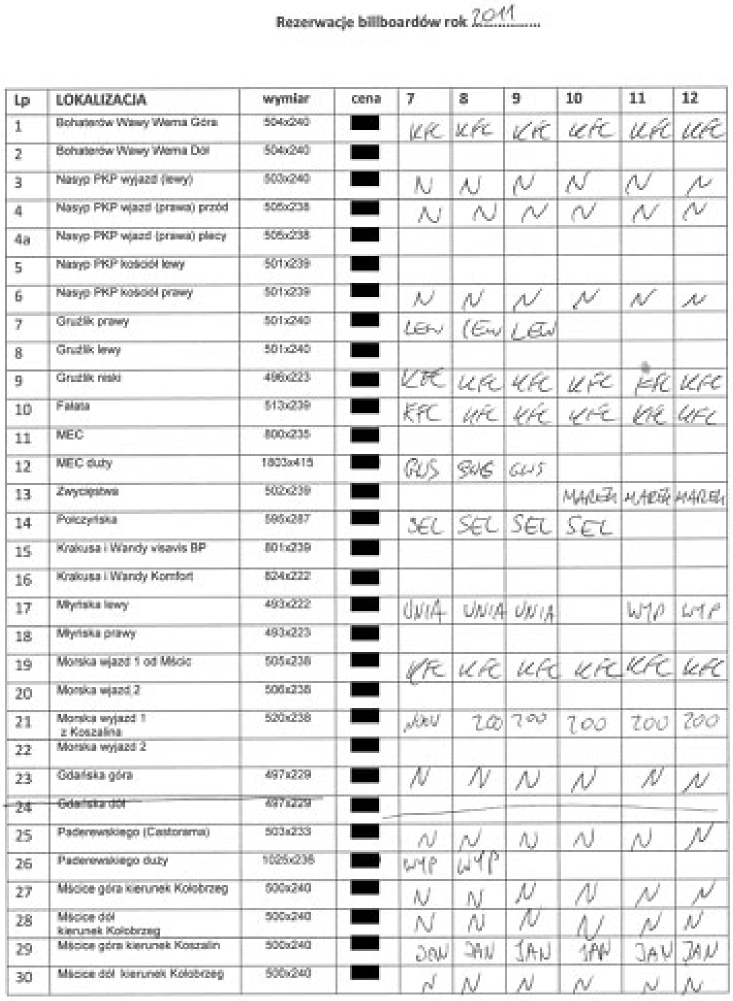
The first part of the article is a response to advertising company demands for Customer Relationship Management system. In the second part the issue of the use of new technologies and estimation the potential benefits arising from the implementation of suggested solution is considered.



Rezerwacje billboardów rok 2011

Lp	LOKALIZACJA	wymiar	cena	7	8	9	10	11	12
1	Bohaterów Wawy Wema Góra	504x240	[redacted]	KFC	KFC	KFC	KFC	KFC	KFC
2	Bohaterów Wawy Wema Dół	504x240	[redacted]						
3	Nasyp PKP wyjazd (lewy)	503x240	[redacted]	N	N	N	N	N	N
4	Nasyp PKP wjazd (prawa) przód	505x238	[redacted]	N	N	N	N	N	N
4a	Nasyp PKP wjazd (prawa) plecy	505x238	[redacted]						
5	Nasyp PKP kościół lewy	501x239	[redacted]						
6	Nasyp PKP kościół prawy	501x239	[redacted]	N	N	N	N	N	N
7	Gruźlik prawy	501x240	[redacted]	LEW	LEW	LEW			
8	Gruźlik lewy	501x240	[redacted]						
9	Gruźlik niski	496x223	[redacted]	KFC	KFC	KFC	KFC	KFC	KFC
10	Fałata	513x239	[redacted]	KFC	KFC	KFC	KFC	KFC	KFC
11	MEC	800x235	[redacted]						
12	MEC duży	1803x415	[redacted]	GUS	GUS	GUS			
13	Zwycięstwa	502x239	[redacted]				MARLEN	MARLEN	MARLEN
14	Połczyńska	595x287	[redacted]	SEL	SEL	SEL	SEL		
15	Krakusa i Wandy visavis BP	801x239	[redacted]						
16	Krakusa i Wandy Komfort	824x222	[redacted]						
17	Młyńska lewy	493x222	[redacted]	UNIA	UNIA	UNIA		WYP	WYP
18	Młyńska prawy	493x223	[redacted]						
19	Morska wjazd 1 od Mścic	505x238	[redacted]	KFC	KFC	KFC	KFC	KFC	KFC
20	Morska wjazd 2	506x238	[redacted]						
21	Morska wyjazd 1 z Koszalina	520x238	[redacted]	JAN	200	200	200	200	200
22	Morska wyjazd 2		[redacted]						
23	Gdańska góra	497x229	[redacted]	N	N	N	N	N	N
~~24~~	~~Gdańska dół~~	~~497x229~~	[redacted]						
25	Paderewskiego (Castorama)	503x233	[redacted]	N	N	N	N	N	N
26	Paderewskiego duży	1025x236	[redacted]	WYP	WYP				
27	Mścice góra kierunek Kołobrzeg	500x240	[redacted]	N	N	N	N	N	N
28	Mścice dół kierunek Kołobrzeg	500x240	[redacted]	N	N	N	N	N	N
29	Mścice góra kierunek Koszalin	500x240	[redacted]	JAN	JAN	JAN	JAN	JAN	JAN
30	Mścice dół kierunek Kołobrzeg	500x240	[redacted]	N	N	N	N	N	N

Fig. 1. Reservation sheet

1.1. Popular CRM software overview

Existing solutions such as “ProfitCRM”, „Asystent CRM” or „Enova Firma” include extended base of products and contractors data. Systems have many modules supporting customer service, but do not allow products (billboards) reservation. Modules containing calendars and reminders allow to book products, but it is a too time consuming and inconvenient solution. The amount of unnecessary modules is another factor speaking for implementation of dedicated software, containing only necessary functions.

1.2. Problem statement

Presented here is the advertising company whose main service is renting billboards. Their requirement is to produce software that allows advert booking along with the possibility of continuous and remote access to data. The application must be independent from the operating system. The company has a limited budget, so there is a need to select the cheapest solution. The following question is considered:

Whether using available information technology is possible to design a system that supports customer relationship management referring to their business processes and to meet their expectations?

2. DEVELOPING DEDICATED CRM SOFTWARE

The first issue is to identify the area of the company, for which the system is designed. The service included in the project is booking billboards. An office employee cataloged the list of current adverts and customers. Rental of billboards is possible up to 3 years from the date of signing the agreements, due to the uncertainty of lease and rates volatility.

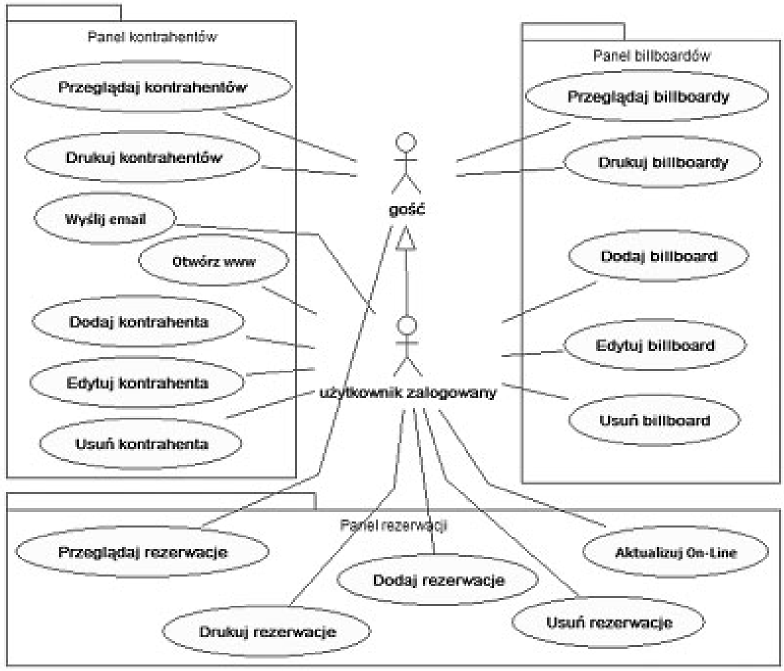


Fig. 2. Use case diagram of system main functionality

Assume that the system is a local application installed on one computer with the internet connection. Online module is placed on hosting provider server (the same where company website is placed). As a result of consultations with the executives, office workers and marketing department the functionality of the system in the form of use case diagram is defined (Figure 2).

The diagram provides the basis for acceptance of the system by the company. The most popular object-oriented programming language that meets the requirements for local application is Java [1]. For online module appropriate language is PHP that allows the display of tabular data and user login [2]. Both Java and PHP are available as free programming languages along with free programming environments and independent platforms that enable the implementation of the planned functionality.

Local application graphic user interface is designed in NetBeans IDE with Swing components (Figure 3). Online module is composed with HTML forms (Figure 4).

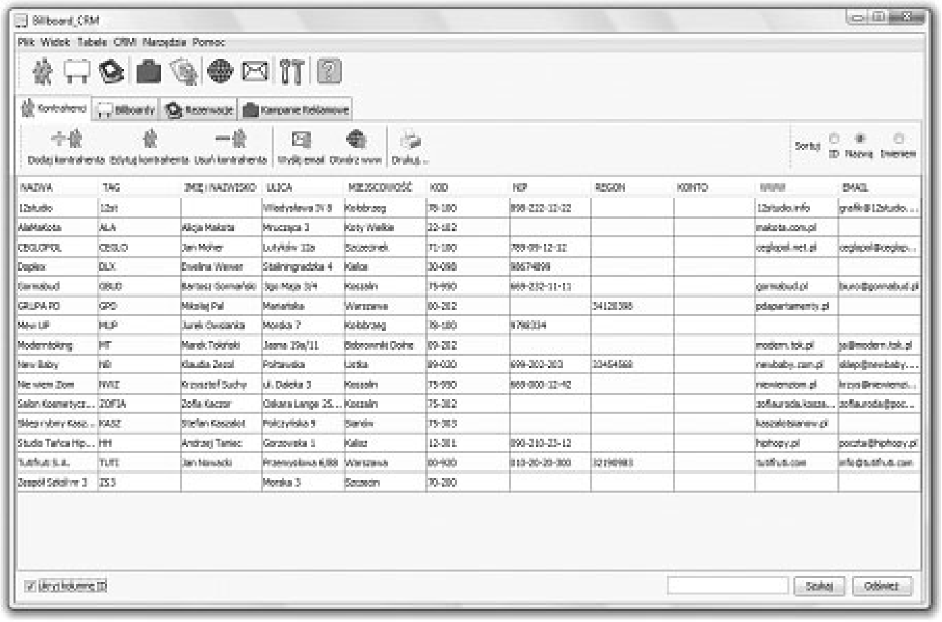


Fig. 3. Application GUI

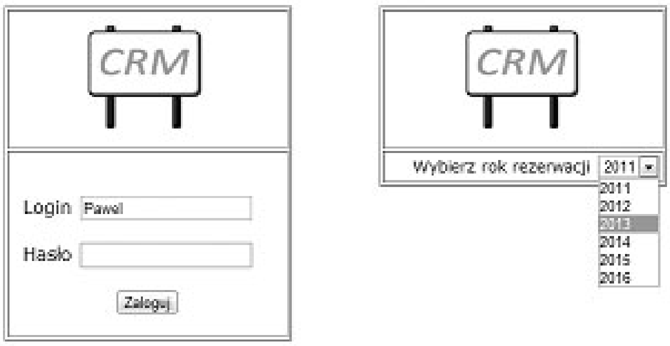


Fig. 4. Online reservation view forms

The basis for the implementation of the application is to design a database for writing and reading data in cooperation with the interface. Relationship database model is designed in Sybase “Power Designer” (Figure 5). The database consists of five entities. Three of them contain attributes identifying customers, billboards and reservations. Two other entities contain logins and passwords.

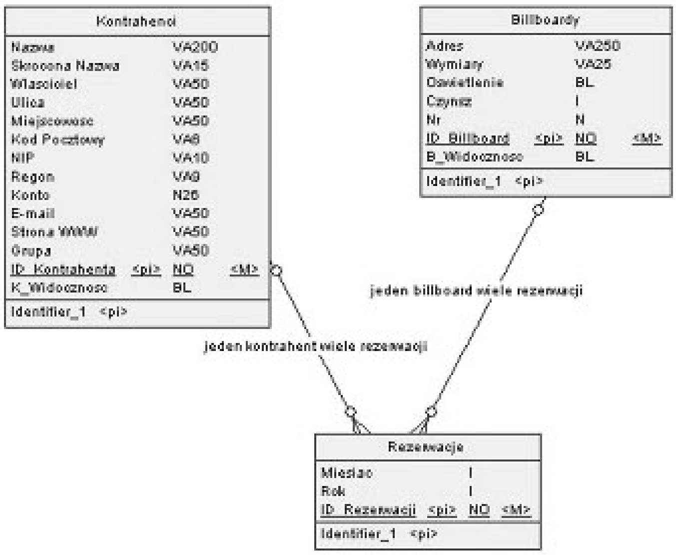


Fig. 5. Contractors, billboards and reservation entities

In order to improve the work of implementation, it is found that some functionality is depended on the other. In the first place the most important modules are designed, as others depend on them.. The first a reservation module (with contractors, billboards and reservation tables), next in random order are online reservation view module, contacts analysis and advertising campaign simulation module.

The reservation module is the most important system element, which allows users to write data of products, clients and reservations. Relating to use case diagram (Figure 2) contractors tables contain functions:

- View contractors table
- Add new contractor data
- Edit existing contractor data
- Delete existing contractor data
- Open selected contractor website in browser
- Send email to selected contractor
- Print contractors table

Billboards table contains functions:

- View billboards table
- Add new billboard data
- Edit existing billboard data
- Delete existing billboard data
- Print billboards table

Reservation table presents rental year selected by the dropdown list. The first three columns contain the data from the billboards entity (symbol, address, and dimension). The next columns are the reservation months. Reservation table functions are:

- View reservation table
- Add new reservation
- Delete existing reservation
- Update online reservation data

The element that distinguishes the designed application from other programs is the use of modules suited to the needs of the advertising company. These modules are an advertising campaign simulation and the analysis of customer contacts.

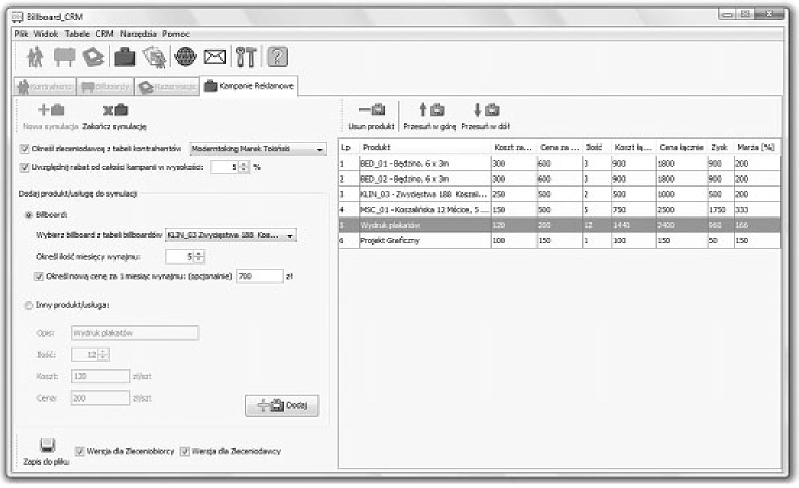


Fig. 6. Advertising campaing simulation window

The advertising campaign simulation is a tool for office workers to calculate profits and losses of the billboard campaign. The user is able to determine the amount of billboards (or other products), prices, rental period (Figure 6). Campaigns can be saved to text files in two versions – for the company and for their client (Figure 7).

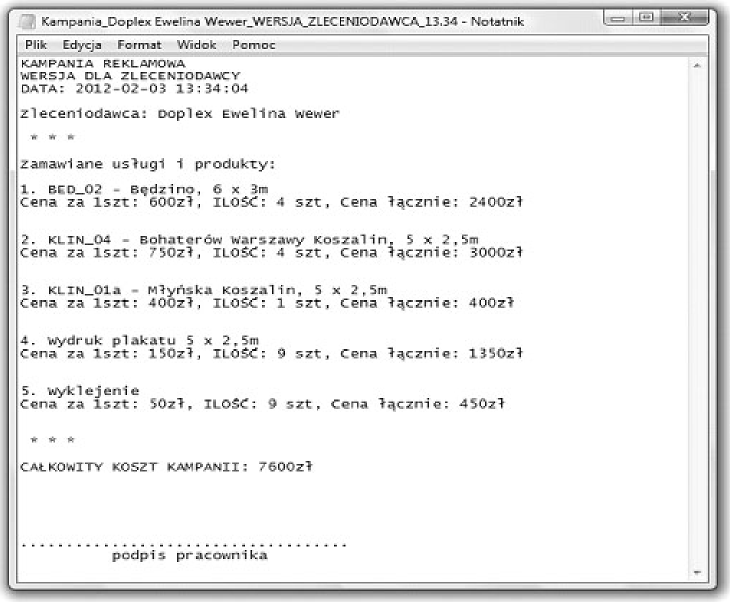


Fig. 7. Advertising simulation campaign text file output

The analysis of the contact with the client consists of a window divided into three panels: billboards, contractors and reservations (Figure 8). Each panel displays statistics associated with rental of billboards by contractors.

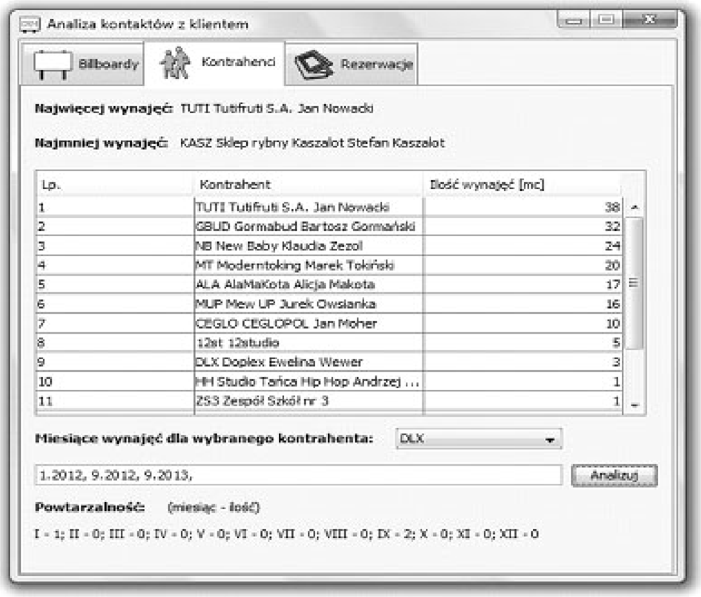


Fig. 8. Analysis of customer contacts window

Tests of designed system allowed the detection of some errors. Sample CRM system errors that are detected and eliminated:

- view another booking year than selected in dropdown list,
- not including the rebate on the advertising campaign simulation,
- wrong assigned menu items to their functions.

Implementation of the finished CRM system to company is divided into few processes:

- PostgreSQL Database Management System installation,
- Java Development Kit installation,
- CRM system installation (on PC),
- online reservation view module installation (FTP account),
- application startup and configuration,
- database fill with billboards and clients data,
- company personnel training of system usage.

Successful implementation of CRM system inclines executives and company employees to consider further expansion of the application. The company constantly develops, increases number of billboards and workers operating reservation system. Company executives are considering the possibility of integrating CRM with applications to create contracts and a financial and accounting system. Frequent problems with hardware failures put the company on additional costs because reinstallation of the CRM system is needed.

The following question arises: is there a technology that meets the rising requirements of the client and that reduces costs and time of system reinstallation and updates? There is such technology and it's Cloud Computing.

3. DESCRIPTION OF CLOUD COMPUTING

Cloud Computing refers to applications and services offered over the Internet. These services are offered from data centers all over the world, which generally are referred to as the "cloud" [3]. The idea of CC simplifies many network connections and computer systems involved in online services. Users with an Internet connection can access the cloud and the services it provides. Since these services are often connected, users can share information between multiple systems and with other users. Cloud Computing includes (e.g.):

- online backup,
- social services,
- personal data services,
- online applications,

- hardware services,
- mirrored websites.

Cloud Computing contains service models (Figure 9), deployment models (Figure 10) and five essential characteristics (Figure 11). Three CC service models:

- Software as a Service **-** cloud users could access an applications through network, not requiring installation and running software on their computers,
- Platform as a Service **-** for cloud developers to rent hardware, operating systems, storage and network capacity, allows the customer to rent virtualized servers and associated services for running existing or developing applications and testing new ones [4],
- Infrastructure as a Service - is a model in which the cloud provider rents the IT equipment like storage, hardware, servers and networking components [5].

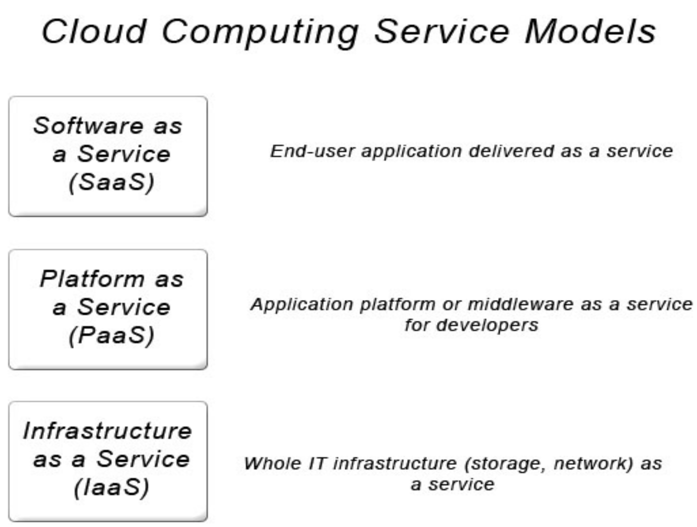


Fig. 9. Cloud Computing service models

Deployment models of CC [6]:

- private cloud - infrastructure is operated solely for an organization and it may be managed by the organization,
- community cloud - infrastructure is shared by several organizations and supports a specific community that has shared concerns,
- public cloud - infrastructure is available to the general public or a large industry group and is owned by an organization selling cloud services,

- hybrid cloud - infrastructure is a composition of two or more clouds (private, community, or public).

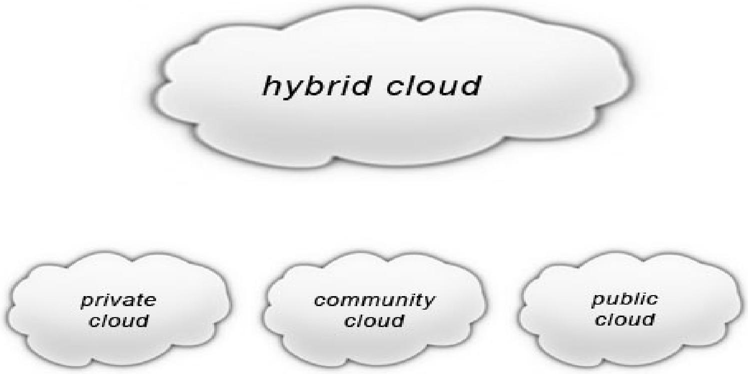


Fig. 10. Cloud Computing deployment models

Five essential characteristics of Cloud Computing (Figure 11) [7]:
- on-demand self-service - CC clients can self-control computing capabilities, such as server time or network storage,
- broad network access - capabilities are available over the network and accessed through standard mechanisms like client applications,
- rapid elasticity **-** capabilities can be rapidly and elastically provisioned (in some cases automatically) to quickly scale out and rapidly released to quickly scale in, depending of customer requirements,
- resource pooling **-** the provider's computing resources are pooled to serve multiple consumers. Different physical and virtual resources are dynamically assigned and reassigned according to consumer's demand,
- measured service - cloud systems automatically control and optimize resource use by leveraging a metering capability.

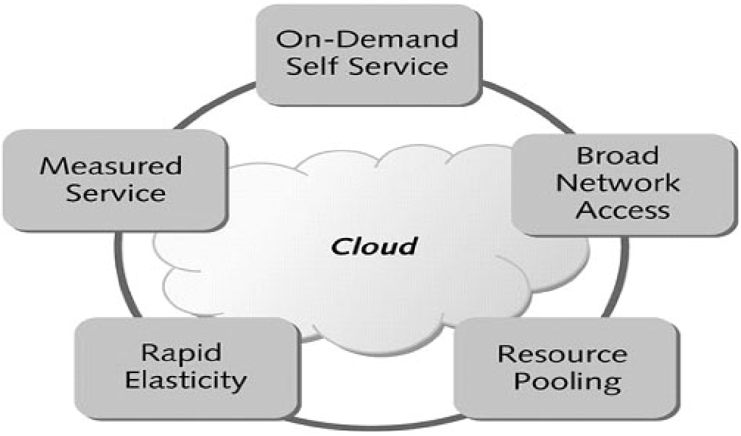


Fig. 11. Cloud Computing characteristics

4. CRM SOFTWARE IN CLOUD COMPUTING

According to GetApp.com CRM's are the most frequently purchased business applications available in Cloud Computing [8]. The most popular is "Zoho CRM" which is provided in 3 editions [9]:

- free edition – for 3 users, 100000 records, free to use,
- professional edition – unlimited users and records, additional features, subscription for 12$/month,
- enterprise edition – available all features for unlimited users, subscription for 25$/month.

"Zoho CRM" gives the ability to customize modules to the needs of the customer from the administration panel. Application includes panels (e.g.) of products, contractors, campaigns, orders or reports. Combining calendar with contractors and products gives the possibility to reserve adverts. Graphical user interface (Figure 12) is simple and intuitive to use. "Zoho CRM" only requires a Web browser installed on any operating system.

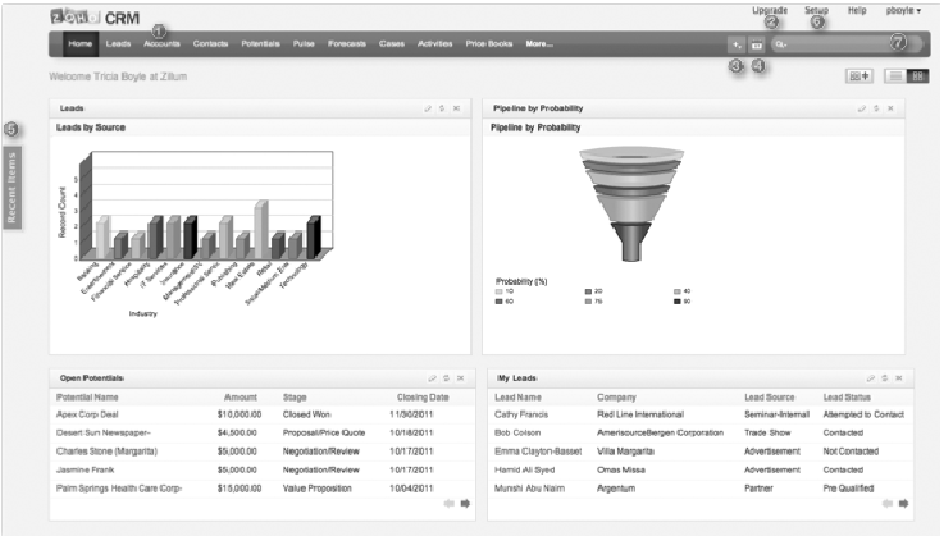


Fig. 12. "Zoho CRM" home page

The use of available on the market SaaS application by the advertising company is an option, but the main issue is that advert booking system is too complicated. Office workers and company's executives are accustomed to actual booking system. Transferring designed local application with well known reservation module to Cloud Computing is considered.

5. MANUFACTURED CRM SYSTEM AS A CLOUD COMPUTING SOFTWARE

Chapter 2 describes the stages of manufacturing of a local application with online module for small advertising company. Chapters 3 and 4 describe Cloud Computing technology and capabilities of the selected CRM. Now consider the impact on the company using the CRM system as the service provided remotely via Cloud Computing and SaaS model.

Direct transfer designed local CRM to SaaS model from a technical point of view is not possible. Cloud Computing and SaaS model requires the use of technology for Web applications, for example PHP, ASP.NET Java EE [2], [10], [11]. Developing CRM application for SaaS model can be based on requirements analysis (company business processes haven't changed) or graphic user interface (graphic elements like images and icons move to the Web application, reproduce the layout of the interface components). Online reservation view module is redundant in this case, the user has a remote access to full application functionality.

The benefits for the advertising company using the CRM application in the cloud:

- accessibility - many users can simultaneously use the application through multiple devices (computers, laptops, smartphones)[12],
- reduce spending on technology infrastructure in case of new systems extensions (CC scalability),
- employees of the Marketing Department can make simulations of advertising campaigns directly at customers' headquarters,
- the booking data are constantly updated,
- accessing the SaaS CRM system requires only a device with internet browser [12].

Mentioned benefits are for implementation CRM system into SaaS model, but there are some risks [13]:

- security,
- data leakage,
- data loss,
- CC provider viability.

Security and data leakage are risks not only for SaaS model application, but also for not carefully used local application. Cloud Computing provider viability and data loss are the biggest drawbacks against the SaaS model implementation.

6. SUMMARY AND CONCLUSIONS

Designed and implemented application matches the current requirements of the advertising company. The application can be classified as a CRM system, as it provides the necessary tools to make customer service better and faster. Individual booking system together with online view module has allowed for the computerization of work and move away the paper sheets. Due to the need for implementation of the new requirements a transition from a local application to the web application is planned. That transition would solve some technical problems and reduce costs.

The benefits of sharing Software as a Service can greatly reduce the production of local applications. The direction in which IT moves shows that a significant number of the programming companies begin to produce software in Web technologies compatible with Cloud Computing. Manufacturing applications in SaaS model instead of the local application is an option that allows to adapt better to increasing customers requirements.

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Galerkin approximation, dimensional reduction, heat conduction.

*Krzysztof NAKONIECZNY**

A GALERKIN APPROXIMATION METHOD INCLUDING SPACE DIMENSIONAL REDUCTION - APPLIED FOR SOLUTION OF A HEAT CONDUCTION EQUATION

Abstract

A multivariate data fitting procedure, based on the Galerkin minimization method, is studied in this paper. The main idea of the developed approach consists in projecting the set of data points from the original, higher-dimensional space, onto a line section. Then, the approximation problem is solved in the resulting one-dimensional space. The elaborated recipe can be designed so that it is computationally more efficient than the schemes based on the least squares minimization. The performance of the method is studied by comparison with the least squares and the moving least squares procedures in a number of examples, including the solution of the heat diffusion equation.

1. INTRODUCTION

Numerical solution of engineering and scientific problems is most often equivalent to solution of some approximation task. In the framework of standard finite element method (FEM) this is accomplished by defining interpolation functions over local subdomains of various shapes, and these functions are frequently chosen from the space of polynomials. Examples can be found in the textbooks [1][2]. In the area of mesh-free or grid-free methods, broadly discussed in the paper [3] and subsequently, for example, in the work [4], local representation of an unknown function is commonly obtained by using the least squares or the weighted least squares fit. If the weight function is defined at each point at which the approximation is to be evaluated then such an approach is named the moving least squares (MLS) method and is thoroughly characterized in the reference [5]. Further insight into the method can be found

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in the work [6], where the analysis of error estimates is given. The benefits of the MLS fit are well reflected by its wide application range, incorporating the solution schemes for the partial differential equations.

Excellent smoothing properties of the MLS fit is occupied, however, by increased computation times, relative to the performances of the other approximation methods. Therefore, efforts are undertaken to improve its efficiency, and the work reported in [7] can serve as an example. An improvement of the MLS methodology, named the approximate MLS approximation, is also discussed in a series of papers including references [8] and [9]. This method has advantage of being matrix-free for a certain class of problems and therefore robust. Its disadvantage of being not enough exact for irregularly spaced data seems to be overcame by iterated approximations described in the report [10].

A somewhat different approach to approximation of multivariate data is studied in the current paper. Its main idea consists in projection of the set of data points from the original, higher-dimensional space onto a line section. Then, instead of the least squares minimization, the Galerkin minimization procedure is applied for finding the coefficients of approximation function. Certain gain in the computational efficiency can thus be attained, as the solution of an approximation problem is accomplished in a dimensionally reduced space. The description of the method is given in the two-dimensional setting, but it seems to be straight forward applicable also to more variables.

2. GALERKIN FIT

A set of scattered function-value data $F = \{F_j(\mathrm{x}_j) : \mathrm{x}_j \in \mathrm{D}, j=1\ldots\mathrm{n}\}$ is defined on a closed domain $\mathrm{D} \subseteq \mathrm{R}^d$. For simplicity of presentation, it is assumed throughout the paper that d=2. A local approximant $\zeta=\mathrm{p(x)a}$ to the data F is built by using a polynomial approximation basis $\mathrm{p}=[p_1,p_2,\ldots,p_\mathrm{m}]$, which is linear [1,x,y] when m=3, quadratic $[1,x,y,xy,x^2,y^2]$ if m=6 or it may be any other complete basis. The vector of coefficients a is to be established in the fitting procedure, which is outlined below.

First, the approximation errors are defined by $\Delta F_j = \mathrm{p}(\mathrm{x}_j)\mathrm{a} - F_j(\mathrm{x}_j)$ for each node in the original region D. Then, the nodes are projected onto a line section $\Lambda \subseteq \mathrm{R}^1$, where they are distributed equidistantly, as illustrated in Fig. 1.

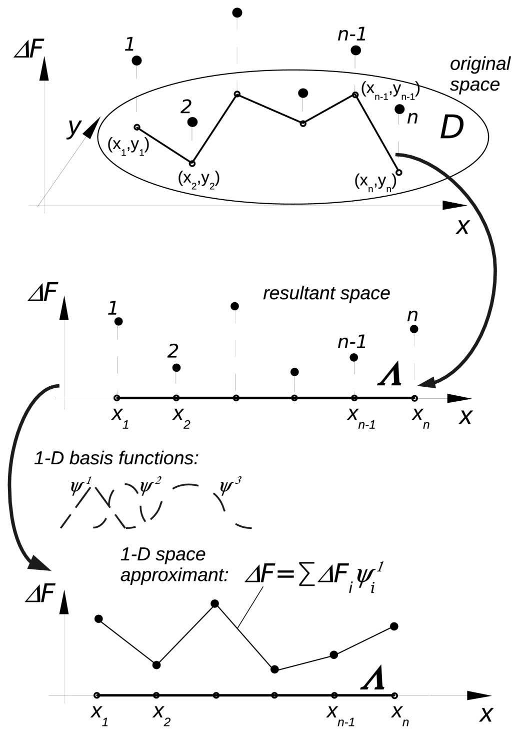

Fig. 1. The idea of approximation by using space dimensional reduction

The equidistant distribution of the nodes on Λ is an arbitrary assumption of the developed method, originating from the observation that only the nodal values themselves - and not the distances between the points - are quantities being unchanged in the projection.

An approximation subspace $V_n = \{\psi_j^b(\mathrm{x}),\ j=1\ldots n\}$ is then associated with Λ, where the basis functions ψ_j^b are simple 'hat' functions if b=1 or are higher order polynomials. Now, the 'distribution' of the approximation error in the resultant one-dimensional subspace can be expressed in terms of the basis ψ_j^b as follows:

$$\Delta F = \sum_j [p(x_j)a - F_j]\psi_j^b(x), \tag{1}$$

where x={x,y} represents the original coordinates and x is the coordinate measured along Λ. Consequently, the Galerkin minimization is performed for each node i=1…n, according to the expression

$$\int_{\Lambda} \Delta F \cdot \psi_i^b dx = \int_{\Lambda} \sum_j [p(x_j)a - F_j]\psi_j^b(x) \cdot \psi_i^b(x) dx \tag{2}$$

and when usual transformations are done, a linear matrix equation is obtained, which contains the unknown coefficients a,

$$\mathbf{Ca} = b \quad . \tag{3}$$

In the above equation, the elements of matrix C are given by the expressions $C_{ik} = \sum A_{ij} p_k(x_j)$, where $A_{ij} = \int_{\Lambda} \psi_i^b \psi_j^b dx$, vector a contains m unknowns a_1, $a_2 \ldots a_m$ and the right-hand-side vector elements are defined by relations $b_k = \sum_j A_{kj} F_j$. It is clear, that the number of nodes should be greater or equal to the dimension of the approximation space ($n \geq m$). Therefore, the matrix C has dimension $n \times m$ and to solve the above equation, one can proceed as follows. If $n=m$ then a simple interpolation problem is solved. If $n=m+1$, the row corresponding to the central node can be added to each other row and then the equation (3) can be solved with a quadratic matrix C. If $n>m+1$, the above procedure can be repeated for the central node and the excessive rows, corresponding to the nodes which are most distant from the central one, can be summed up together to obtain an $m \times m$ matrix again.

Alternatively, the procedure can be presented in a form of projection, resulting in the following compact representation of the approximant:

$$\zeta = \mathbf{pa} = \mathbf{pC}^{-1} b = \mathbf{pC}^{-1} \mathbf{AF} = \Phi F \quad , \tag{4}$$

or, in a more detailed version,

$$\zeta = \sum_k \varphi_k F_k \quad , \tag{5}$$

with the basis functions defined by

$$\varphi_k = \sum_{j=1}^{m} (C^{-1} A)_{kj} p_j \quad . \tag{6}$$

At this point, a short reference to the standard FEM, LS and MLS methods seems to be due. In each case, the approximation problem is defined by matrices C=AP, where P=[p_1, p_2,…, p_n]^T, and Φ=p(C^{-1}A), but the matrix A has various compositions, depending on the method, which can be found, for example, in the textbook [2]. Particularly, $A_{LS}=P^T$, $A_{MLS}=P^TW$, where W is a diagonal matrix containing weights and A_{FEM}=I (an identity matrix). It follows from our previous considerations that A_{Gal} is a tridiagonal matrix, composed of triplets (1/6, 2/3, 1/6), if ψ_i^b are linear functions (b=1), and has greater bandwidth, if ψ_i^b are higher-order polynomials.

The above remarks can be concluded with the statement, rather commonly apprehended, that, if computational efficiency is considered, the FEM is the most competitive among the methods and the MLS is the least effective one. The Galerkin fit with its tridiagonal matrix A_{Gal} follows the FEM. Another order of precedence is most probably predicated when the methods are compared in terms of their approximation accuracy. This issue is studied further in the text, where the results of a number of numerical tests are presented.

3. GALERKIN FIT APPLIED FOR SOLVING A HEAT CONDUCTION EQUATION

An approach to derive an approximate solution to the unsteady heat conduction equation is studied below. The problem is defined in the spatio-temporal region D × $\langle 0, t_{tot}\rangle$, where t_{tot} denotes the total computing time. With the temperature $T=T(\mathrm{x}, t)$ as the main variable and with constant material properties μ, the governing equation for heat conduction, together with the boundary and initial conditions, is as follows:

$$
\begin{aligned}
\frac{\partial T}{\partial t} &= \mu\nabla^2 T \quad \text{in } \mathbf{D}\times\langle 0, t_{tot}\rangle, \\
T &= f(x,t) \quad \text{on } \partial\mathbf{D}\times(0, t_{tot}\rangle, \\
T &= T_0 \quad \text{in } \mathbf{D}\times\{0\},
\end{aligned}
\tag{7}
$$

where ∂D denotes the boundary of the region D.

An approximated solution to the above differential equation can be obtained by coupling spatial discretization, performed with the developed method, with any recipe for temporal differentiation. In this exemplary application, the simplest algorithm suitable for performing comparison tests among the studied methods is chosen. Thus, the Euler time differencing algorithm yields the scheme

$$\tilde{T}_i^{+} = \tilde{T}_i + \Delta t\cdot(\mu\nabla^2 T)_i\ , \tag{8}$$

where $\tilde{T}_i$ and $\tilde{T}_i^+$ denote the initial condition and the approximated solution at *i*-th node, respectively, and the term $\mu\nabla^2 T$ is expressed in the local basis defined by Eq. (6) as follows:

$$(\mu\nabla^2 T)_i = \mu\sum_k (\nabla^2\varphi_k)\tilde{T}_k \ , \tag{9}$$

where k=1, 2…i…n are indexes of the nodes surrounding, and include, the node i.

This way a point collocation method is obtained (cf. [2]), however, application of the weighted Galerkin formulation for the spatial approximation is also not precluded. Consequently, the Eq. (8) can serve for the comparison among the four above discussed methods in terms of their approximation quality. This issue is addressed in the next section.

4. TESTS AND RESULTS

4.1. Local approximation errors

In the first group of tests, the local Galerkin fit has been compared with the least squares (LS) and the moving least squares (MLS) methods. The comparison has been based on an interpolation example analyzed by Zienkiewicz [2], illustrated here in Fig. 2 with filled circles.

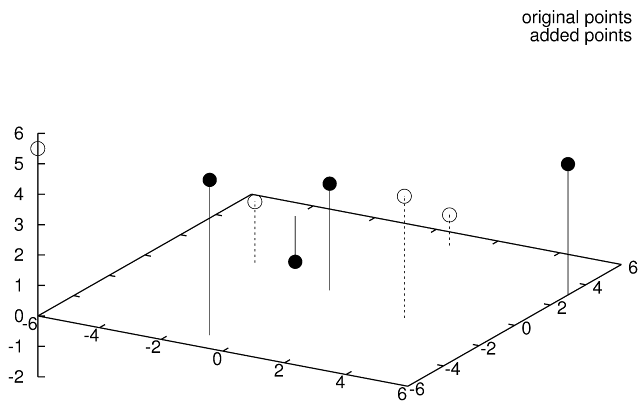

Fig. 2. Data set for the comparison test

Additional points are introduced for the purpose of the current study, to enable approximations to be done with the 2-nd order polynomials, and these points are illustrated in Fig. 2 with the empty circles. An ill (singular) pattern of nodes is realized by relocating one of them to obtain four nodes alined.

Tables 1-2 show approximation errors computed for the singular and non-singular nodal patterns. The Galerkin methodology is performed by relying on the linear (ψ_i^1 = Gal) basis functions, illustrated in Fig. 1. In all the cases the quadratic approximation basis p is used, so *m*=6. Table 1 shows the results for the 6-node setup of nodes, i.e. for the interpolation case. The Galerkin fit is for that case more efficient than the LS and MLS techniques, however, for singular pattern of nodes, it gives worse results than its counterparts.

Tab. 1. Interpolation errors: 6 nodes

	normal setup		singular setup	
method	central node	mean	central node	mean
LS	0	0	1.053	6.473
MLS	0	0	0.264	2.499
Gal	0	0	-1.472	8.129

Tab. 2. Approximation errors: 8 nodes

	normal setup		singular setup	
method	central node	mean	central node	mean
LS	0.144	0.115	1.000	0.426
MLS	0.013	0.227	0.265	1.511
Gal	0.125	0.192	2.212	1.261

Table 2 itemizes the errors for the 8-node stencils. The superior performance of the MLS fit over all other methods is observed at the central node. However, if the mean error is studied, the best results are found for the LS approximation method, followed by Gal fit. A 7-node stencil has been studied also, but the results of Galerkin method in this case were more unsatisfactory.

4.2. Solution of the heat conduction equation

The above discussed methods are now applied for the solution of heat conduction problem described in the preceding section. The differential equation (7) has been solved under the initial condition $T(x,y,0)=sin(\pi x)+sin(\pi y)$ and with the boundary conditions $T(0,y,t)=T(1,y,t)=exp(-\mu\pi^2 t)\cdot sin(\pi y)$ and $T(x,0,t)=T(x,1,t)=exp(-\mu\pi^2 t)\cdot sin(\pi x)$. The analytical solution to this problem is given by the function $T(x,y,t)= exp(-\mu\pi^2 t)\cdot(sin(\pi x)+sin(\pi y))$.

The computations have been performed using regular and random distribution of nodes in the domain D, which is shown in Fig. 3. The random distribution of the nodes is obtained by applying the following transformation to the regular nodes (x_i,y_i):

$$x_i^{'} = x_i + r \cdot dx \cdot s\,, \tag{10a}$$

$$y_i^{'} = y_i + r \cdot dy \cdot s\,, \tag{10b}$$

where r is a random number generated with C function drand48(), dx and dy are fractions (here 0.15) of the inter-nodal distances, and s=1 or s=-1, depending on the location of r within the interval $\langle 0,1 \rangle$ subdivided into ten equal subintervals.

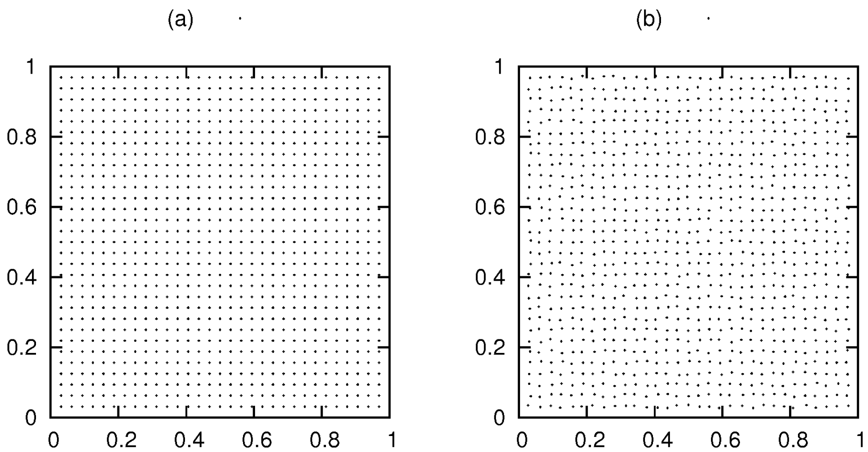

Fig. 3. Regular (a) and irregular (b) nodal arrangements for the heat conduction test

The convergence of the method (8) is illustrated, respectively, in Fig. 4 and in Fig. 5 in terms of the L_2-norm error. Each figure contains two plots, for the 6- and 8-node local approximation setups. The errors are plotted for the three above discussed approximation approaches. It should be mentioned that the approximation nodes are collected around each local center in an automatic manner. Searching algorithms from the ANN library [11] are used for that purpose.

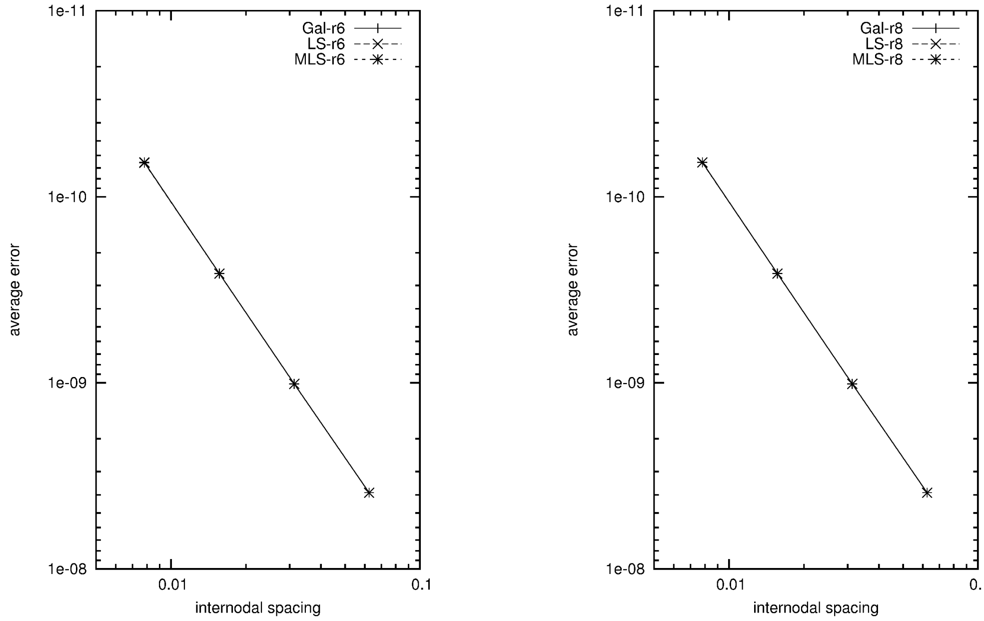

Fig. 4. Convergence plots of the average error for the regular arrangement of nodes

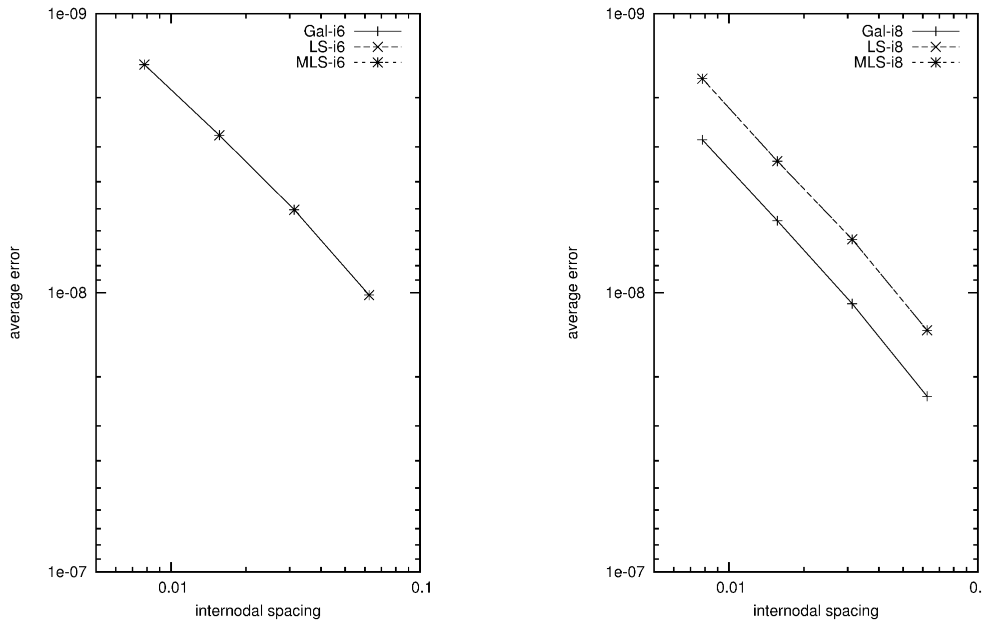

Fig. 5. Convergence plots of the average error for the irregular arrangement of nodes

A second-order convergence is attained uniformly by all the methods when the nodes are distributed regularly, see the curve inclination on the plots in Fig. 4. With the irregular nodal arrangement, the convergence deteriorates to about 1-st order, and the Gal approximations are a little less accurate then the least squares methods.

5. CONCLUSIONS

From the present study, the following conclusions can be drawn. The approximation method based on dimensional reduction and Galerkin minimization yields results comparable to the LS and MLS methods.

The developed method is computationally more efficient than the LS and MLS fits and attains similar accuracy, whether the nodes are distributed regularly or irregularly in the 2-D region, using 2-nd order polynomials and 6- or 8-node stencils.

The method has been successfully applied in a mesh-free, automatic, explicit solver of the unsteady heat conduction equation. It seems that the obtained results are encouraging to undertake further investigations in this area, including approximation in 3-D domains, other approximation bases and other applications.

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model, dynamic system, shaft, elastic deformable condition, equation, operational transmittance, regulator

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MATHEMATICAL MODEL OF IDENTIFICATION AND AUTOMATION THE PROCESS OF SHAFT MACHINING IN ELASTIC-DEFORMABLE CONDITION

Abstract

The specification of the low rigidity parts machining process is consider by introducing suitable equations of constrains, which describe additional elastic deformations in one of equations describing the force controlling influence. This paper introduces general and detailed mathematical models of the DS of turning the longitudinal, low rigidity shafts. Research results and examples of their approximation were introduced. Some method of synthesis and examples structure of regulator P were shown for one detailed model of DS under received approximated operational transmittance of DS. The way of controlling the accuracy of shafts turning in the elastic deformable condition and controlling system was described.

1. INTRODUCTION

Continued efforts aimed at obtaining high-quality machining on machine tools under conditions of various interferences affecting the technological system (TS) have led to the application of adaptive control (AC) systems in the machine-building industry [1, 2]. The problem of improvement of such systems is particularly relevant under ESP conditions, in the realization of so-called "no-man" technology. Development of a mathematical model (MM) of control object (CO) in the dynamics, adequate to the original object, is a prerequisite for substantiated approach to the solution of the problem of analysis of stability

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of automatic control systems (ACS) or AC and synthesis of correcting elements, in accordance with required quality indices of transition process control. Whereas, in similar systems, indexes of quality of control of the input variable – elastic deformation in the dynamic TS - characterize directly the errors of shape of the machined parts, determined by the effect of rapidly changing interferences of the type of change in material allowance for machining or variability of the physicochemical properties of the machined material.

The dynamic system (DS) of the process of machining is a technological system –i.e. a machine tool together with the realized technological process (TP) of machining (turning, grinding, drilling, milling) [3, 5].

In the identification of DS the systemic approach includes the following fundamental stages [5]:

- analysis of input data for the identification;
- formulation of control strategy oriented at a specific subsystem of basic machine tools, in accordance with input data in designing ACS, AC;
- exclusion of invariant, relative to their spectrum, input effects of subsystems and components within the limits of technical capability of ACS, AC and the machine tools;
- analysis of possible structures of *MM* of control system with respect to their function, types of components and connections between them, number of levels of hierarchy, principles of connection, and permanence of the connections.

With a lack of sufficiently complete and detailed information on the object of control, calculated characteristics may significantly differ from the true ones. The parameters (settings) of regulators adopted in designing do not guarantee the required quality of control, or even stability of the system. Apart from this, the analysed systems are characterized by extensive variability of parameters of the CO. Those determinations indicate the complexity of the problem of ensuring stability of the ACS and the necessity of taking special care in the approach to the problem of defining its structure and synthesis of the corrective devices.

2. IDENTIFICATION OF DYNAMIC SYSTEMS OF SHAFT TURNING

In the case when there is complete information on the object of control it is possible to design a model using the analytical method. Such a procedure, leading to the identification of the structure and parameters of a model, is referred to as the analytical identification. For complex systems, development of MM with the analytical method frequently requires additional experimental tests aimed at the verification of theoretical results and at determination of some of the model parameters.

The presented schematic of the structure of MM shows that the basic scope of work in the design of MM is based on in-depth theoretical analysis of connections between the variable parameters and on revealing the relationships describing the processes taking place within the object.

The possibility of linearization of equations of motion of the particular components of the DS follows also from the commonly accepted view that assurance of high requirements with respect to precision of adjustment is reduced to realization of adjustment systems operating at “small” deviations of variables. Therefore, the dynamic system of the process of drilling can be considered as multi-dimensional CO with subsystems in the form of the technological process and an elastic system. The structure of the CO includes circuits of feedbacks from the elastic system caused by force effects that appear in the course of realization of the technological process.

References [4, 5, 6] present a system of equations and a generalized structural schematic of MM of the dynamic system of shaft turning. The developed system of equations and the structural schematic of MM take into account the geometry of the machined layer and of the machining force in turning, elastic properties of the TS, process of forming of cross-section of the machined layer (ML). The process of forming of cross-section of the ML takes into account the phenomenon of machining “following the feed ridge” which consists in that the components of the machined layer of the material at the current moment are defined by the temporary position of the cutting edge and by its coordinates at the moment of the preceding revolution of the semi-finished product, i.e. at a time-lag of a single revolution. At the same time the effect of elastic deformation for coordinate Z on the depth of turning is taken into account.

The process of forming of the cross-section of ML is under strong effect of the phenomenon of machining “following the feed ridge” and by elastic deformations in the DS. The process of forming of ML cross-section can be described with a system of integral-differential equations with delayed argument. Variables characterizing the ML cross-section depend on the input variables and on the elastic deformation in the DS. In the vector of the technological variables, formed by the dynamic system, two components can be distinguished – one defined by the vector of input effects and the other by the vector of elastic deformations.

Elements of the vector of input values are the control values in the form the straight feed rate, rotational speed of the machined part, and also interference in the form of changes in the hardness of the machined material and in the machining allowance relative to the length and diameter of the machined part.

The vector of elastic deformations is determined by the vectors of machining forces and of control values entering the system of vibrational stability assurance. Dynamic properties of the equivalent elastic system can be approximated with quadratic equations [7]. The choice of the vector of technological variables is significantly affected by the phenomenon of machining “following the feed ridge”, manifest in that the momentary values of the components of the said vector are determined by the values of elements of the input vector and of the vector of elastic deformations not only at the current moment but also at the time of the preceding revolution of the machined part. Due to this the dynamic system is described with a system of integral-differential equations with variable delayed argument.

As a result of analysis of the processes occurring in the dynamic system of machining a system of equations and functions of transition were obtained, as well as the generalized structure of the control object.

2.1. Identification of turning of low-rigidity shafts

To improve the precision of machining of shafts with low rigidity, technological methods were developed for the control of machining precision, based on change in the elastic-deformable condition [8, 9]. As control effects, in accordance with the developed classification [9], particular force control effects are employed, or their combinations – axial and eccentric tension, control by means of additional force effects aimed at compensation of force factors from the machining process, bending moments at supports, control of force-induced bending-torsional strain.

MM of various technological systems of machining with control of the elastic-deformable status for stabilised parameters, presented in the form of deflection functions, were obtained with the assumption that a banding force acting on the machined part is an external variable that is independent of the elastic deformations in the DS. This approach is based on not including the closing of the elastic system through the process of machining and does not introduce new errors into results of analyses of static characteristics of the CO. Analysis of the structure of a suitable MM of a control object for transition parameters is not possible without taking into consideration the specifics of processes within the machining zone and the closing of the DS through the process of machining.

MM of the considered control object – DS with control of the elastic-deformable status of parts with low rigidity was constructed on the basis of general principles of creating MM of DS [4, 5, 6] of machining, with the specifics of the process of machining of parts with low rigidity being accounted for by the introduction of suitable equations of constraints [5, 11, 12], reflecting mutual relationships between additional elastic deformations Δg_{ξ}, into one of the equations representing the force control effects of the system of equations.

Equivalent elastic deformations of the *TS* in the machining of parts with low rigidity can be represented in the form of two components:

$$g_{\zeta} = g_{\zeta obr.} + g_{\zeta cz.} \ , \tag{1}$$

where: $g_{\zeta obr.}$ and $g_{\zeta cz.}$ – elastic deformations of the machine tool, fixture, tool and part for each coordinate, respectively; $\zeta \in \{x, y, z\}$.

The first component in this expression for the TS under consideration is, in principle, lower by one order of magnitude and can be neglected.

Elastic deformations of the TS in the radial direction g_y in accordance with the deflection equations [8], at set parameters without the inclusion of closed status of the CO, may be considered as a deterministic non-linear function of the part parameters L, d, EI; components of the machining force F_c, F_p, F_f; coordinates x of machining force application on the length of the semi-finished product and various regulatory effects in the form of: tensile force F_{x1}; eccentric tensile force creating two regulatory effects F_{x1} and moment $M = F_{x1} \cdot e$, where e - eccentric of the tensile forces; one or more additional forces $F_{dod.i}$; bending moments M_i; torsional moment M_{skr} or their combinations:

$$g = f(L, d, EI, F_c, F_p, F_f, F_{x1}, e, F_{dod.i}, M_i, M_{skr}, x) \ . \tag{2}$$

Assuming that the true feed rate and the rate of change of coordinate x are relatively small, in the analysis of transition processes the change in coordinate x in the function of time can be left out. Therefore, relation (2) in the operator form can be written as:

$$\begin{aligned} g_y(s) = {} & K_{xy} \cdot F_f(s) + K_{yy} \cdot F_p(s) + K_{zy} \cdot F_c(s) + K_{F_{x1}} \cdot F_{x1}(s) + \\ & + K_e \cdot e(s) + K_{F_{dod.i}} \cdot F_{dod.i}(s) + K_{M_i} \cdot M_i(s) + K_{M_{skr}} \cdot M_{skr}(s) \end{aligned} \ , \tag{3}$$

where: dual indexes at coefficients K mean that coefficients K_{xy}, K_{zy} indicate the effect of increase in the values of components F_f, F_c on increase in the level of elastic strain on coordinate y; $K_e = K_e^{'} \cdot F_{x1_0}$.

The gain coefficients of linear equations are defined as fragmentary derivatives of the strain function along the respective coordinate. For example, for the TS of machining with the effect of axial tensile force F_{x1}, causing the elastic-deformable condition, from the system of elastic deformations we obtain [5, 11]:

$$K_{yy} = \left(\frac{\partial g_y}{\partial F_p} \right)_0 = \frac{L^3 \cdot [1 - \cos(2\pi x_0 / L)]^2}{2\pi^2 \cdot (4\pi^2 \cdot EI + F_{x1_0} \cdot L^2)} \ , \tag{4}$$

$$K_{F_{x1}} = \left(\frac{\partial g_y}{\partial F_{x1}}\right)_0 = -\frac{F_p \cdot L^5 [1-\cos(2\pi x_0 / L)]^2}{2\pi^2 \cdot (4\pi^2 \cdot EI + F_{x1} \cdot L^2)} = -\frac{g_{y_0} \cdot L^2}{4\pi^2 \cdot EI + F_{x1} \cdot L^2} \quad , \tag{5}$$

where: F_{x1_0}, g_{y_0} – values of tensile force and elastic strain of the part along coordinate y at the point of linearization (values of variables relative to which increases of variables are given).

In the special case under consideration the remaining coefficients in relation (3) are equal to zero. Coefficients of gain, corresponding to different DS at various methods of loading (i.e. with axial-radial bending and various methods of fixing) in machining of elastic-deformable parts, obtained in an analogous manner, are presented in [5, 11] – x_0 - coordinate of cutting edge position on machining length at the point of linearization [5, 11]. The additional elastic strains g_x, g_z with respect to coordinates x and z, as a result of the action of the control force effects under consideration, basically do not have any significant effect on the dynamic properties of the CO and can be treated as negligible.

In accordance with the result of studies in ref. [13], the components of machining force without inclusion of the contact strain at the surface of application are written as:

$$F_c = Q_{pw} \cdot a \cdot b \,, \quad F_p = Q_{pw} \cdot a \cdot b \cdot K'_y \,, \quad F_f = Q_{pw} \cdot a \cdot b \cdot K'_x \,,$$

where: Q_{pw} – relative work of formation of shaving,

K'_y, K'_x – constant coefficients for given conditions of machining.

Hence

$$m_z = \left(\frac{\partial F_c}{\partial a}\right)_0 = Q_{pw_0} \cdot b_0 \cdot K_z \;,\; m_y = \left(\frac{\partial F_p}{\partial a}\right)_0 = Q_{pw_0} \cdot b_0 \cdot K_y \;,$$

$$m_x = \left(\frac{\partial F_f}{\partial a}\right)_0 = Q_{pw_0} \cdot b_0 \cdot K_x \quad n_z = \left(\frac{\partial F_c}{\partial b}\right)_0 = Q_{pw_0} \cdot a_0 \cdot K_z \,,$$

$$n_y = \left(\frac{\partial F_p}{\partial b}\right)_0 = Q_{pw_0} \cdot a_0 \cdot K_y \;,\; n_x = \left(\frac{\partial F_f}{\partial b}\right)_0 = Q_{pw_0} \cdot a_0 \cdot K_x$$

and

$$n_y m_x = Q_{pw_0} a_0 K_y Q_{pw_0} b_0 K_x \ , \quad m_z n_x = Q_{pw_0} b_0 K_z Q_{pw_0} a_0 K_x \ ,$$

$$m_y n_x = Q_{pw_0} b_0 K_y Q_{pw_0} a_0 K_x \ , \quad n_z m_x = Q_{pw_0} a_0 K_z Q_{pw_0} b_0 K_x \ ,$$

$$n_y m_x = m_y n_x \ , \quad m_z n_x = n_z m_x \ .$$

The relations given above permit simple transformations of coefficients A and B included in corresponding operator transmittances (OT) of the CO with relation to various control and interfering effects.

In referenced works [5, 11, 12] the authors analysed the possibility of replacing the obtained relations of OT with approximated ones, application of which significantly simplifies calculation of characteristics of DS MM. The analysis was made according to the criterion of recreation of true characteristics of MM with approximated relations in the time and frequency planes; it was demonstrated that the form of approximating relations should be chosen taking into account the numerical value of coefficient B. It was also determined that the value of $B = 0{,}1$ is the "limit" at which the switch from one form of approximating relation to another is justified. The value of coefficient B is defined as the ratio of rigidity of equivalent elastic system to gain coefficients of the process of machining and can be adopted as an index of relative rigidity of DS. Broad ranges of variability of machining parameters on machine tools, e.g. of change in the hardness of the machined material, machining allowance, cutting edge geometry, determine broad ranges of variability of coefficients $m_x, m_y, K_{\kappa_r}, K_x, K_{yy}$ and B, respectively.

Calculations show that in machining of low-rigidity shafts and in roughing and profiling of parts with normal rigidity the values of coefficient B are notably greater than the limit value of $B = 0{,}1$; in this case also the approximating relations for OT according to (11), (14), (15) should be built by splitting the exponential function $e^{-s\tau}$ into a Pade series which, keeping the first two components, may be written as:

$$e^{-s\tau} = \left(1 - \frac{1}{2} s \cdot \tau + \frac{1}{12} s^2 \cdot \tau^2\right) \Big/ \left(1 + \frac{1}{2} s \cdot \tau + \frac{1}{12} s^2 \cdot \tau^2\right) \ . \qquad (6)$$

In the case of control of the elastic-deformable condition of parts with low rigidity through the application of tensile force F_{x1} the structure of CO has been developed in [5, 11].

On the basis of the schematic given in [5, 11], after transformation, the relation for OT of the dynamic system when increase in elastic deformations g_y in the radial direction is adopted as the initial variable is reduced to the form of:

$$G_{F_{x1}}(s) = \frac{g_y(s)}{F_{x1}(s)} = K_0 \cdot \frac{1 + A' \cdot (1 - e^{-s\tau})}{1 + B' \cdot (1 - e^{-s\tau})} \quad , \tag{7}$$

where: $K_0 = K_{F_{x1}} \cdot \dfrac{1}{1 + K_{yy} \cdot n_y + K_{xy} \cdot n_x + K_{bz} \cdot K_z \cdot n_z}$, (8)

$$A' = m_x \cdot K_x + K_{\kappa_r} \cdot m_y \cdot K_y \quad , \tag{9}$$

$$B' = \frac{m_x \cdot K_x + K_{\kappa_r} \cdot m_y \cdot K_{yy} \left[2 + K_{yy} \cdot n_y + K_{bz} \cdot n_z + K_{xy} \cdot m_x / (K_{yy} \cdot m_y) + K_{bz} \cdot K_z \cdot m_z / (K_{yy} \cdot m_y)\right]}{1 + K_{yy} \cdot n_y + K_{xy} \cdot n_x + K_{bz} \cdot K_z \cdot n_z} . \tag{10}$$

For known values of coefficients included in relations (7) – (10), the relations can be notably simplified. Calculations show that in machining of parts with low rigidity with application of force effects components containing K_{bz} and K_{xy} can be basically left out. In such a situation, the relation for B' gets considerably simplified, and the expression for coefficients K_0 is notably reduced. Denominator of OT of operator transmittance for DS determined from the relation in control of straight feed [4, 6] is reduced, as shown above, to the form of denominator of aperiodic component of the first or second order. To transform the numerator of OT to a typical form one can also employ splitting the function $e^{-s\tau}$ into a Pade series, and then the analysed OT will assume the form of:

$$G_{F_{x1}}(s) = K_0 \cdot \frac{T_3^2 \cdot s^2 + T_3' \cdot s + 1}{(T_1 \cdot s + 1) \cdot (T_2 \cdot s + 1)} \quad , \tag{11}$$

The time constants T_1 and T_2 are determined from the relation:

$$T_{1,2} = 0{,}5\tau \cdot \left[0{,}5 + B \pm \sqrt{(0{,}5 + B)^2 - 1/3} \right] \tag{12}$$

by substituting in it B' to replace B, and the time constants in the numerator are then equal to:

$$T_3 = 0{,}289\tau; T_3' = (0{,}5 + A')\cdot\tau \quad . \tag{13}$$

2.2. Simplification of mm of dynamic system of shaft turning in the elastic-deformable condition

Further transformations of the numerator of OT (7) should be made with the inclusion of time constants T_3 and T_3' which depend on A'. If $A' < 0{,}077$, then the OT of UD can be written in the following typical form:

$$G_{F_{x1}}(s) = \frac{g_y(s)}{F_{x1}(s)} = K_0 \cdot \frac{T_3^2 \cdot s^2 + 2\varepsilon \cdot T_3 \cdot s + 1}{(T_1 \cdot s + 1)\cdot(T_2 \cdot s + 1)} \quad , \tag{14}$$

where: ε – coefficient of attenuation

$$\varepsilon = \frac{0{,}5 + A'}{0{,}577} \quad . \tag{15}$$

In the case when $A' \geq 0{,}078$, the approximating relation for the analysed OT assumes the form of:

$$G_{F_{x1}} = \frac{g_y(s)}{F_{x1}(s)} = K_0 \cdot \frac{(T_4 \cdot s + 1)\cdot(T_5 \cdot s + 1)}{(T_1 \cdot s + 1)\cdot(T_2 \cdot s + 1)} \quad , \tag{16}$$

where: $T_{4,5} = 0{,}5\tau \cdot \left[0{,}5 + A' \pm \sqrt{(0{,}5 + A')^2 - 1/3}\right]$.

In an analogous way, on the basis of the generalized structural schematic and system of equations [5, 11] models of DS were obtained for other control effects. The approximating relations of dynamic system OT for various control effects differ from those presented here only in the value of the gain coefficient K_0 of the CO. Instead of coefficient $K_{F_{x1}}$ in relation (8) for K_0, in such a case coefficients of gain for the respective effects $K_e, K_{F_{dod.i}}, K_{M_i}, K_{M_{skr.}}$ are inserted. The values of those coefficients can be calculated according to the relations given in [5, 11].

In many cases, with accuracy sufficient for practical engineering calculations, approximating relations for OT (7) should be built with the use of the first component of the splitting of function $e^{-s\tau}$ into a Pade series:

$$e^{-s\tau} = (1 - \frac{1}{2} s \cdot \tau)/(1 + \frac{1}{2} s \cdot \tau) \quad . \tag{17}$$

Table 1 presents operator transmittances, coefficients of gain and time constants for the generalized and the detailed MM of dynamic system for the turning of low-rigidity shafts in the elastic-deformable condition [5, 11].

Tab. 1. Operator transmittances, coefficients of gain and time constants of generalized and simplified MM of dynamic system of turning of shafts with low rigidity in elastic-deformable condition

No	$K_{\kappa_r} \neq 0, \quad \kappa_r \neq 90^\circ$			$K_{\kappa_r} = 0, \quad \kappa_r = 90^\circ$		
	Dynamical System Operator Transmittance	**Coefficient of Gain**	**Time Constants**	**Dynamical System Operator Transmittance**	**Coefficient of Gain**	**Time Constants**
1	**2**	**3**	**4**	**5**	**6**	**7**
1	**Using first two elements of Padé Approximation for** $e^{-s\tau}$**:** $G_{T1}(s) = K_0 \frac{T_3^2 s^2 + T_3' s + 1}{(T_1 s + 1)(T_2 s + 1)}$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y}$ $A_1 = m_x K_x + m_y K_y K_{\kappa_r}$ $B_1 = [m_x K_x + K_{\kappa_r}(m_y K_y + m_x K_{xy} +$ $+ K_{xy}n_x K_y m_y) + K_{bz}K_z K_{\kappa_r}(m_z +$ $+ n_z m_y K_y + K_{yy}m_y K_{\kappa_r}(1 + n_y K_y)]/$ $/(1 + K_{xy}n_x + K_{bz}K_z n_z + K_{yy}n_y)$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_1 \pm$ $\pm\sqrt{(0{,}5 + B_1)^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $T_3' = (0{,}5 + A_1)\tau$	**Using first two elements of Padé Approximation for** $e^{-s\tau}$**:** $G'_{T1}(s) = K_0 \frac{T_3^2 s^2 + T_3' s + 1}{(T_1 s + 1)(T_2 s + 1)}$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y}$ $A_1' = m_x K_x$ $B_1' = \frac{m_x K_x}{1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y}$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_1' \pm$ $\pm\sqrt{(0{,}5 + B_1')^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $T_3' = (0{,}5 + A_1')\tau$
1	$m_x K_x << 1$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y}$ $A_2 = m_y K_y K_{\kappa_r}$ $B_2 = \{K_{\kappa_r}(m_y K_y + K_{xy}n_x m_y K_y) +$ $+ K_{xy}m_x(K_{\kappa_r} - n_x K_x) + K_{bz}n_z K_z \times$ $\times[K_{\kappa_r}n_z m_y K_y + m_z(K_{\kappa_r} - n_x K_x)] +$ $\times[K_{\kappa_r}n_z m_y K_y + m_z(K_{\kappa_r} - n_x K_x)] +$ $/(1 + K_{xy}n_x + K_{bz}K_z n_z + K_{yy}n_y)$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_2 \pm$ $\pm\sqrt{(0{,}5 + B_2)^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $T_3' = (0{,}5 + A_2)\tau$	$G'_{T1}(s) = K_0 \frac{T_3^2 s^2 + 2\varepsilon T_3 s + 1}{(T_1 s + 1)(T_2 s + 1)}$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y}$ $A_2' = 0$ $B_2' = n_x K_x(m_z K_{bz}K_z + m_x K_{xy} +$ $+ m_y K_{yy})/$ $/(1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y)$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_2' \pm$ $\pm\sqrt{(0{,}5 + B_2')^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $T_3' = 0{,}5\tau$ $\varepsilon = \frac{T_3'}{2T_3} = 0{,}866$
1	$m_x K_x << 1, \quad K_{bz}n_z K_z << 1$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{yy}n_y}$ $A_2 = m_y K_y K_{\kappa_r}$ $B_3 = \{K_{\kappa_r}(m_y K_y + K_{xy}n_x m_y K_y) +$ $+ K_{xy}m_x(K_{\kappa_r} - n_x K_x) +$ $+ K_{yy}m_y(K_{\kappa_r} - n_x K_x)\}/$ $/(1 + K_{xy}n_x + K_{yy}n_y)$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_3 \pm$ $\pm\sqrt{(0{,}5 + B_3)^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $T_3' = (0{,}5 + A_2)\tau$		$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{yy}n_y}$ $A_2' = 0$ $B_3' = n_x K_x(m_x K_{xy} + m_y K_{yy})/$ $/(1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y)$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_3' \pm$ $\pm\sqrt{(0{,}5 + B_3')^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $T_3' = 0{,}5\tau$ $\varepsilon = 0{,}866$
1	$K_{xy} << 1$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{yy}n_y}$ $A_2 = m_y K_y K_{\kappa_r}$ $B_4 = [K_{yy}m_y K_{\kappa_r}(n_y K_y + 1) +$ $+ K_{yy}m_y(K_{\kappa_r} - n_x K_x)/(1 + K_{yy}n_y)$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_4 \pm$ $\pm\sqrt{(0{,}5 + B_4)^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $T_3' = (0{,}5 + A_2)\tau$		$K_0 = \frac{K_{F_{x1}}}{1 + K_{yy}n_y}$ $A_2' = 0$ $B_4' = n_x K_x K_{yy}m_y/(1 + K_{yy}n_y)$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_3' \pm$ $\pm\sqrt{(0{,}5 + B_3')^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $T_3' = 0{,}5\tau$ $\varepsilon = 0{,}866$
2	$A_1 << 0{,}077$ $G'_{T1}(s) = K_0 \frac{T_3^2 s^2 + 2\varepsilon T_3 s + 1}{(T_1 s + 1)(T_2 s + 1)}$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y}$ $A_1 = m_x K_x + m_y K_y K_{\kappa_r}, \quad B_1 = B_1$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_1 \pm$ $\pm\sqrt{(0{,}5 + B_1)^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $\varepsilon = \frac{0{,}5 + A_1}{0{,}577}$	$G'_{T1}(s) = K_0 \frac{T_3^2 s^2 + 2\varepsilon T_3 s + 1}{(T_1 s + 1)(T_2 s + 1)}$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y}$ $A_1' = m_x K_x$ $B_1' = \frac{m_x K_x}{1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y}$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_1' \pm$ $\pm\sqrt{(0{,}5 + B_1')^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $\varepsilon = \frac{0{,}5 + A_1}{0{,}577}$
2	$m_x K_x << 1, \ A_2 << 0{,}077$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y}$ $A_2 = m_y K_y K_{\kappa_r}, \quad B_2 = B_2$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_2 \pm$ $\pm\sqrt{(0{,}5 + B_2)^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $\varepsilon = \frac{0{,}5 + A_2}{0{,}577}$	$G'_{T1}(s) = K_0 \frac{T_3^2 s^2 + 2\varepsilon T_3 s + 1}{(T_1 s + 1)(T_2 s + 1)}$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{bz}n_z K_z + K_{yy}n_y}$ $A_2' = 0, \quad B_2' = B_2'$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_2' \pm$ $\pm\sqrt{(0{,}5 + B_2')^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $\varepsilon = 0{,}866$
2	$m_x K_x << 1, \ K_{bz}n_z K_z << 1$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{yy}n_y}$ $A_2 = m_y K_y K_{\kappa_r}, \quad B_3 = B_3$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_3 \pm$ $\pm\sqrt{(0{,}5 + B_3)^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $\varepsilon = \frac{0{,}5 + A_2}{0{,}577}$		$K_0 = \frac{K_{F_{x1}}}{1 + K_{xy}n_x + K_{yy}n_y}$ $A_2' = 0, \quad B_3' = B_3'$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_3' \pm$ $\pm\sqrt{(0{,}5 + B_3')^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $\varepsilon = 0{,}866$
2	$K_{xy} << 1$	$K_0 = \frac{K_{F_{x1}}}{1 + K_{yy}n_y}$ $A_2 = m_y K_y K_{\kappa_r}, \quad B_4 = B_4$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_4 \pm$ $\pm\sqrt{(0{,}5 + B_4)^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $\varepsilon = \frac{0{,}5 + A_2}{0{,}577}$		$K_0 = \frac{K_{F_{x1}}}{1 + K_{yy}n_y}$ $A_2' = 0, \quad B_4' = B_4'$	$T_{1,2} = 0{,}5\tau[0{,}5 + B_4' \pm$ $\pm\sqrt{(0{,}5 + B_4')^2 - 1/3}\ ]$ $T_3 = 0{,}289\tau$ $\varepsilon = 0{,}866$

Tab. 1. Operator transmittances, coefficients of gain and time constants of generalized and simplified MM of dynamic system of turning of shafts with low rigidity in elastic-deformable condition (continued)

1	2	3	4	5	6	7
3	$A_1 \geq 0{,}078$ $G_{T2}(s) = \frac{(T_4 s+1)(T_5 s+1)}{T_1 s+1)(T_2 s+1)}$	$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{bz}n_zK_z+K_{yy}n_y}$ $A_1 = m_xK_x + m_yK_yK_{\kappa_r}$, $B_1 = B_1$	$T_{4,5} = 0{,}5\tau[0{,}5 + A_1 \pm \pm\sqrt{(0{,}5+A_1)^2 - 1/3}\ ]$ $T_{1,2} = 0{,}5\tau[0{,}5 + B_1 \pm \pm\sqrt{(0{,}5+B_1)^2 - 1/3}\ ]$	$G'_{T2}(s) = \frac{(T_4 s+1)(T_5 s+1)}{T_1 s+1)(T_2 s+1)}$	$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{bz}n_zK_z+K_{yy}n_y}$ $A_1' = m_xK_x$, $B_1' = B_1'$	$T_{4,5} = 0{,}5\tau[0{,}5 + A_1' \pm \pm\sqrt{(0{,}5+A_1')^2 - 1/3}$ $T_{1,2} = 0{,}5\tau[0{,}5 + B_1' \pm \pm\sqrt{(0{,}5+B_1')^2 - 1/3}$
3	$m_xK_x << 1$, $A_2 \geq 0{,}078$	$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{bz}n_zK_z+K_{yy}n_y}$ $A_2 = m_yK_yK_{\kappa_r}$, $B_2 = B_2$	$T_{4,5} = 0{,}5\tau[0{,}5 + A_2 \pm \pm\sqrt{(0{,}5+A_2)^2 - 1/3}\ ]$ $T_{1,2} = 0{,}5\tau[0{,}5 + B_2 \pm \pm\sqrt{(0{,}5+B_2)^2 - 1/3}\ ]$	$G'_{T1}(s) = K_0 \frac{T_3^2 s^2 + 2\varepsilon T_3 s + 1}{(T_1 s+1)(T_2 s+1)}$	$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{bz}n_zK_z+K_{yy}n_y}$ $A_2' = 0$, $B_2' = B_2'$	$T_{1,2} = 0{,}5\tau\left[0{,}5 + B_2' \pm \pm\sqrt{(0{,}5+B_2')^2 - 1/3}\ \right]$ $T_3 = 0{,}289\tau$ $\varepsilon = 0{,}866$
3	$m_xK_x << 1$, $K_{bz}n_zK_z << 1$	$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{yy}n_y}$ $A_2 = m_yK_yK_{\kappa_r}$, $B_3 = B_3$	$T_{4,5} = 0{,}5\tau[0{,}5 + A_2 \pm \pm\sqrt{(0{,}5+A_2)^2 - 1/3}\ ]$ $T_{1,2} = 0{,}5\tau[0{,}5 + B_3 \pm \pm\sqrt{(0{,}5+B_3)^2 - 1/3}\ ]$		$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{yy}n_y}$ $A_2' = 0$, $B_3' = B_3'$	$T_{1,2} = 0{,}5\tau\left[0{,}5 + B_3' \pm \pm\sqrt{(0{,}5+B_3')^2 - 1/3}\ \right]$ $T_3 = 0{,}289\tau$ $\varepsilon = 0{,}866$
3	$K_{xy} << 1$	$K_0 = \frac{K_{F_{x1}}}{1+K_{yy}n_y}$ $A_2 = m_yK_yK_{\kappa_r}$, $B_4 = B_4$	$T_{4,5} = 0{,}5\tau[0{,}5 + A_2 \pm \pm\sqrt{(0{,}5+A_2)^2 - 1/3}\ ]$ $T_{1,2} = 0{,}5\tau[0{,}5 + B_4 \pm \pm\sqrt{(0{,}5+B_4)^2 - 1/3}\ ]$		$K_0 = \frac{K_{F_{x1}}}{1+K_{yy}n_y}$ $A_2' = 0$, $B_4' = B_4'$	$T_{1,2} = 0{,}5\tau\left[0{,}5 + B_4' \pm \pm\sqrt{(0{,}5+B_4')^2 - 1/3}\ \right]$ $T_3 = 0{,}289\tau$ $\varepsilon = 0{,}866$
4	**Using the first element of Padé Approximation for** $e^{-s\tau}$**:** $G_{T3}(s) = K_0 \frac{T_2 s+1}{T_3 s+1}$	$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{bz}n_zK_z+K_{yy}n_y}$ $A_1 = m_xK_x + m_yK_yK_{\kappa_r}$, $B_1 = B_1$	$T_0 = \tau$, $T_1 = 0{,}5\tau$ $T_2 = \tau(0{,}5 + A_1)$ $T_3 = \tau(0{,}5 + B_1)$	**Using the first element of Padé Approximation for** $e^{-s\tau}$**:** $G_{T3}(s) = K_0 \frac{T_2 s+1}{T_3 s+1}$	$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{bz}n_zK_z+K_{yy}n_y}$ $A_1' = m_xK_x$, $B_1' = B_1'$	$T_0 = \tau$, $T_1 = 0{,}5\tau$ $T_2 = \tau(0{,}5 + A_1')$ $T_3 = \tau(0{,}5 + B_1')$
4	$m_xK_x << 1$	$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{bz}n_zK_z+K_{yy}n_y}$ $A_2 = m_yK_yK_{\kappa_r}$, $B_2 = B_2$	$T_0 = \tau$, $T_1 = 0{,}5\tau$ $T_2 = \tau(0{,}5 + A_2)$ $T_3 = \tau(0{,}5 + B_2)$		$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{bz}n_zK_z+K_{yy}n_y}$ $A_1' = 0$, $B_2' = B_2'$	$T_0 = \tau$ $T_1 = T_2 = 0{,}5\tau$ $T_3 = \tau(0{,}5 + B_2')$
	$m_xK_x << 1$, $K_{bz}n_zK_z << 1$	$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{yy}n_y}$ $A_2 = m_yK_yK_{\kappa_r}$, $B_3 = B_3$	$T_0 = \tau$, $T_1 = 0{,}5\tau$ $T_2 = \tau(0{,}5 + A_2)$ $T_3 = \tau(0{,}5 + B_3)$		$K_0 = \frac{K_{F_{x1}}}{1+K_{xy}n_x+K_{yy}n_y}$ $A_2' = 0$, $B_3' = B_3'$	$T_0 = \tau$ $T_1 = T_2 = 0{,}5\tau$ $T_3 = \tau(0{,}5 + B_3')$
	$K_{xy} << 1$	$K_0 = \frac{K_{F_{x1}}}{1+K_{yy}n_y}$ $A_2 = m_yK_yK_{\kappa_r}$, $B_4 = B_4$	$T_0 = \tau$, $T_1 = 0{,}5\tau$ $T_2 = \tau(0{,}5 + A_2)$ $T_3 = \tau(0{,}5 + B_4)$		$K_0 = \frac{K_{F_{x1}}}{1+K_{yy}n_y}$ $A_2' = 0$, $B_4' = B_4'$	$T_0 = \tau$ $T_1 = T_2 = 0{,}5\tau$ $T_3 = \tau(0{,}5 + B_4')$

3. CONCLUSION

As follows from the performed study, dynamic structures of MM of technological systems for low-rigidity shafts with control of their elastic-deformable condition include, apart from inertial segments characteristic for MM of feed-related control, also overload segments. The occurrence of the overload segments in transmittances of the MM reduces the inertness of the control objects with respect to channels of control of additional force effects. For example, with close values of time constants of the numerator and denominator in relations [12], as happens is numerous cases, the properties of model of CO approach those of the non-inertial segment with transmission coefficient K_0.

It should be emphasized that the discussed mathematical description of the *CO* was made with the exclusion of “small” time constants characterizing the dynamic properties of the process of machining and of the equivalent elastic system. Such an approach is justified as the *ACS* or *AC* circuit includes, apart from the object, also an automatic control device and other components with “large” time constants, whose dynamic properties are highly significant in the solution of the problem of stability analysis and synthesis of corrective segments.

Comparison of MM of the object for various control effects permits the statement that with the application of additional force effects the object has a notably lower inertness compared to the case of control focused on the feed channel. Thanks to this in the *ACS* and *AC* of the elastic-deformable condition of parts higher indexes of control quality can be achieved in the dynamics and there is a possibility of effective counteraction of interference caused by changes in material allowance for machining and in the hardness of machined semi-finished products by varying their rigidity on the length of machining.

The results of theoretical research of object’s time characteristics by channel of additional force reactions, confirm the above-mentioned conclusion, that DS’s properties are, in approximation, equivalent to proportional link when TS’s elastic-deformable condition is being controlled. Such simplification is correct only when “low” and “medium” frequencies (dynamical properties of control process and elastic system are not shown) range is being considered. Time-constants of elastic system and cutting process which define limits of the “medium” frequencies range, are between *0,003s* and *0,005s.* Time-constants of executive element, which are applied during constructing SAC by elastic-deformable condition, usually increase the pointed value by an order of magnitude. Hence, the range of important frequencies is defined by the executive element’s inertia and is localized more to the left than range of frequencies that are defined by dynamical characteristics of considered object.

In case of interferences in the form of exponential-cosines function, the optimum controller for the model is the typical P controller, which proportionality coefficient is defined by selected level of limitations on the control reaction. The hardware realization of PI controller was presented.

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