толщин для различных комбинаций стекол были использованы наиболее эффективные методики расчета [3, 4].

<table>
<thead>
<tr>
<th>( f' ), мм</th>
<th>( \beta_2 )</th>
<th>( d_1 ), мм</th>
<th>( d_2 ), мм</th>
<th>( L ), мм</th>
<th>( \Delta ), мм</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>0.389</td>
<td>17</td>
<td>19</td>
<td>33.35</td>
<td>67.16</td>
</tr>
<tr>
<td>90</td>
<td>0.444</td>
<td>41</td>
<td>080</td>
<td>24.2</td>
<td>91.25</td>
</tr>
<tr>
<td>110</td>
<td>0.498</td>
<td>59</td>
<td>39</td>
<td>18.19</td>
<td>109.44</td>
</tr>
<tr>
<td>160</td>
<td>0.598</td>
<td>84</td>
<td>6</td>
<td>7.11</td>
<td>130</td>
</tr>
</tbody>
</table>

К примеру, рассчитанный первый компонент по методике [4] с оптическими характеристиками: фокусное расстояние \( f' = 135\) мм, диафрагменное число \( f'/D = 3.75 \) обеспечивает совершенную коррекцию сферической аберрации и комы 3-го порядка.

[Рисунок 2 – Суммы Зейделя для первого компонента]

Компьютерное моделирование данного объектива в программной среде Opal показало, что объектив обладает допустимыми значениями осевых и вточечных аберраций (2\( \omega = 4^\circ \)) для всего диапазона изменения фокусного расстояния (70-145мм). Отметим, что получена ортоскопическая коррекция аберраций (величина относительной дисторсии во всех позициях не превышает 1%). Установлено, что базовые композиции трехкомпонентной системы панкратического объектива, рассчитанные в диапазоне фокусных расстояний \( f' = 160-70 \) мм при относительном отверстии \( D/f' = 1:2 \) и поле зрения 
\( 2\omega = 40^\circ \) планируют эффективно использовать для осуществления аберрации и астигматической разности в спектральном диапазоне \( \lambda = 380...680 \) нм. Объективы ахроматизованы при заданной спектральной эффективности. Полученные формулы для трехкомпонентной системы можно успешно использовать для расчета композиций из четырех и пяти компонентов. Для расчета сложных систем переменного увеличения были использованы некоторые теоретические положения метода гауссовых скобок [5].

Область применения предложенной методики можно расширить не только по количеству компонентов, но и для объективов дискретного типа. В этом случае алгоритм будет изменяться в зависимости от компонентов, были получены необходимые дополнительные формулы. Расчет объектива с дискретным изменением фокусного расстояния представляет значительный интерес. На основании предложенных формул выполнен расчет объектива дискретного типа с перепадом 10° – базовую схему, которую можно использовать при проектном расчете объекта, работающем в ИК области или для других применений.

**Литература**


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**ON THE METHODOLOGY OF SUPPORTING MAINTENANCE DEPARTMENT WORK AT A STRATEGIC LEVEL USING MES INFORMATION SYSTEM**

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Employees within the maintenance department in a manufacturing company, especially at the strategic level, have to use innovative methods and tools, in order to work in accordance with the company's development strategy. The tool, that supports the execution of business processes at the operational level and also at the strategic level may be the information system, namely Manufacturing Execution System (MES).

Providing research in the area of the effective use of the MES system in the maintenance department at the strategic level is important due to need the company's management regarding knowledge about the currently state of computerization and automation of the enterprise. The effective use of the MES system may enable further activities in the company related to production automation and also can be the first element of enterprise development according with the Industry 4.0 concept.

The MES system supports the execution of production processes and at the same time it is used to support activities carried out in the maintenance department within the production company.

MES systems enable effective collection of data and information in real time from production business.
processes and their transfer to other processes realised within the enterprise. Data and information on production can be collected directly from machines and from employees working in the production department. The MES system also performs functions of the Supervisory Control and Data Acquisitions System, that can be defined as the unified interface to production controllers and to autonomous industrial systems [1].

The use of selected functionalities of the MES system by the managers of the maintenance department enables the effective obtainment of data and information in real time, e.g. data and information about the realisation of the machine repairs, machine downtime, about the current irregularities occurring during the production process, which are particularly important for the efficiency of maintenance work in a production enterprise. According to [2], the main functions of the MES system are defined as:

- allocation and status of resources,
- sending products,
- data collection and acquisition,
- quality management,
- maintenance management,
- repairs management,
- results analysis,
- scheduling,
- document controlling,
- personnel management,
- process management,
- product tracking.

Among the MES systems offered for Polish manufacturing companies, we can distinguish among others: Wonderware, Queris, ProSeS BDE, PSImes, BPSC or CMMMS. Each IT system supports specific activities performed in a production company, including also carried out in the maintenance department at the strategic and also at the operational level.

The analysis of the use of the MES system at the strategic level in the maintenance department was carried out assuming that the defined activities are carried out by the head of the maintenance department within eight hours of work. The head of the maintenance department supervises the work of 13 employees who serve 380 machines throughout the production enterprise. Production is carried out in the company in two-shift mode.

For analysis of the use of the MES system by employees at the strategic level in the maintenance department in the Polish manufacturing company of the automotive industry, the specific activities are defined which are performed using the MES system.

The partly activities are:
- order management,
- reporting the demand for external service,
- planning downtime,
- monitoring/tracking schedule/production planning,
- identification of bottlenecks on each device,
- review of technical documentation,
- conducting on-line/video training,
- reporting of readiness for work of repaired (after overhaul) devices/machines,
- training planning,
- monitoring of trainings,
- human resources planning,
- creating procedures,
- reporting/signaling improvement solutions (e.g. modernization, improvement of devices),
- reporting/signaling solutions to improve work (e.g. information flow),
- implementing improvement solutions (e.g. modernization, improvement of devices),
- implementing solutions that improve work (e.g. information flow),
- monitoring of technical tests of equipment/machines,
- monitoring MTTR indicator (Mean Time To Repair), MTTR = failure time/number of corrective events (min),
- monitoring MTTF indicator (Mean Time to Failures), MTTF = (available working time – failure time)/number of events (min),
- monitoring MTBF indicator (Mean Time Between Failure), MTBF = MTTR + MTTF.
- analysis of the availability of the device,
- analysis of costs in the maintenance department,
- archiving data.

The completely activities are:
- tracking the status of devices in real time,
- checking the availability of parts in the warehouse,
- reporting the demand for parts/consumables,
- recording of withdrawal of equipment/machines from service,
- generating reports for machines or devices,
- signalling equipment/machine downtime,
- signalling/informing about the readiness of equipment/machines/production line.

The use of the MES system in the maintenance department mainly supports only partly the work at the strategic level. Activities that are fully performed using the MES system are 24.14% of all activities carried out by employees at the strategic level in the maintenance department within 8 hours of daily work (Fig. 1).

Activities performed in the maintenance department at the strategic level using completely the MES information system within 8 hours of work mainly concern tracking the production schedule and order management. When analyzing the time that takes up activities performed in the maintenance department using completely the MES information system, it can be concluded that almost 60% i.e. about 5 hours of work, is supported by information technology. This means that the information system actually supports activities at the strategic level in the maintenance department (Fig. 2), which are performed during a given working day.
Knowing that the effective use of the MES information system can enable automation of production according with the Industry 4.0 concept, research was also conducted on the use of the MES information system at the strategic level during a given work month and during a given year. In a given month/year, the maintenance department manager performs also activities that are not supported by the MES system:

- entering the records on the inspection of equipment/machines,
- registering parts/consumables for equipment/machines,
- monitoring repair of equipment/machines,
- recording/making a selection from the list of actions performed,
- entering the write-up for devices/machines,
- simulation of retooling devices, machines/production lines,
- informing about failure/blockade,
- notification by SMS or E-mail about a planned preventive maintenance, repair,
- generating a manual alarm on failure,
- generating an alarm automatically about a failure,
- notification by SMS/E-mail about a failure,
- running a repair calendar,
- access from console to the desktop of another level,
- monitoring OEE indicator (Overall Equipment Effectiveness),
- recording accidents by work.

Figs. 3 and 4 present the results of the analysis of the use of the MES information system during the month and during the year in the maintenance department at the strategic level.

Analyzing the activities performed in the maintenance department at the strategic level within a month, it can be noticed that the majority of activities of about 50% are partly supported by the MES system, while the fully supported works by the system is only 13.05%, and works performed completely without system support, up to 41.3%.

However, analyzing, activities carried out also at the strategic level, but during the year, there is a decrease the efficiency of the MES system application - it is only 2.17% of operations performed entirely using the system, still partially supported by the system is at the 50% limit, while activities performed without the help of the system is 47.83%.

Based on the research carried out in the maintenance department related to the use of the MES information system at the strategic level, it was found that still only a few activities performed by the manager during the year are supported by information technology. These are activities related to planning and scheduling human resources. The results of the analysis, which concern everyday activities, have shown the efficiency of using the MES system (Figs 1 and 2), but these are not the key activities at the strategic level of the maintenance department manager. Knowing that the maintenance department supports 380 machines in a production company and that work related to real-time device/machine status tracking during the year are among the most important activities at the strategic level and are not supported by the information system, it was found that the production company presented is unfortunately not prepared to implement the concept of industry 4.0. The concept of industry 4.0 assumes the implementation of IT-assisted relationships between employees, objects and systems through the exchange of data and information in real time [3, 4].
In order to be able to implement the objectives of the Industry 4.0 concept, manufacturing companies should make investments in IT technologies supporting the execution of processes (activities), because IT systems are the basis for further investments in smart technologies. The transition to “level 4.0” also requires large investments in supplementing the knowledge of managers and engineers to implement and use the IT technologies supporting production processes.

References