Energy Efficiency in Material Flow Systems (effMFS)

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Automated in-plant Material Flow Systems (MFS) are increasing in most industries. Their energy efficiency becomes high important. After the introduction, we will shortly illustrate the main points of the effMFS research project founded by the Austrian Research Promotion Agency. In section 3 we focus on detailed efficiency studies of different conveyor types. Results of the first research-year are proved by measurement methods and rated potentials for improvements. To improve overall MFS energy efficiency, it is necessary to have indicator standards meeting real life conditions. A discussion of a comprehensive approach of MFS energy efficiency indicator (EEI) model is focused in section 4, including a specific EEI example for conveyors. Finally, the conclusion sums up and gives a lookout to further research.

Keywords: *Material Flow Systems, Conveyor systems, Energy Consumption, Energy Efficiency Indicator, Power Measuring Methods*

1. INTRODUCTION

Material Flow Systems (MFS) are main components of most in-plant logistic systems. Automated MFS are increasing as well as their energy consumption. Energy efficiency becomes highly important, from the point of economy as well as from the overall goal of environmental sustainability [1].

Today there are punctual standards and optimization tasks for efficiency improvements of single elements specified (e.g. electric drives). However, no standards for benchmarking energy consumption of MFS, in relation to characteristic operations, are available. There are only few optimization tasks for overall MFS processed in the past.

At the Institute of Logistics Engineering a research project (titled effMFS) was arranged and started in March 2011 in close cooperation with the industrial partner SSI Schäfer PEEM GmbH – funded by FFG Austrian Research Promotion Agency.

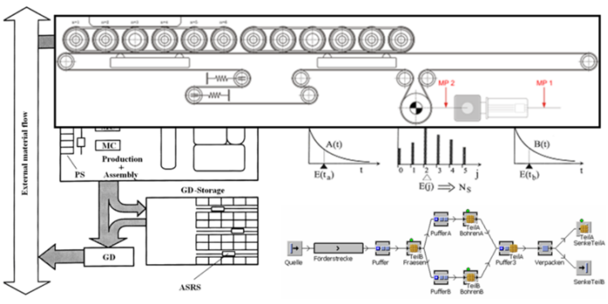

Figure 1. Schemas of a Material Flow System

Figure 1 basically illustrates aspects of the three levels of MFS to optimize: Enterprise Resource Planning (ERP), Manufacturing Execution System (MES), device/component (field).

Improvements of design (e.g. conveyors) must be based on verified potentials, extensive pre-studies and measurement tasks.

In this paper, we present the verified promising results of the first project year of the three. This includes on one hand investigations of different conveyor designs in relation to energy efficiency and potentials for improvements. On the other hand, a conveyor-related approach for standardized energy efficiency indicators and methods to determine them has been worked out.

2. OVERVIEW - OVERALL PROJECT

The published research findings about energy consumption of Material Flow Systems (MFS) and their efficiency most times focus on transportation problems. In general, these results are not portable to intra-logistic systems.

There are no standards available to calculate or measure characteristic energy efficiency indicators for MFS. The available standard methods for determining losses and efficiency meet only single components like electric drives (EN 60034).

The research project focuses on two main areas of interest. First focal point is the overall optimization approach for automated MFS. This includes electric drive technology, detailed designs of drivetrain and mechanical conveyor-systems as well as control and operation strategies to improve energy efficiency.

Second core area is the design of a standardized and generalized model of characteristic values to get the ability to compare energy efficiency of MFS independent from manufacturers and technical solutions. Optimized energy efficiency of MFS becomes possible if efficiency factors in relation to current orders, loads and modes of operation are available. The specific power consumption at nominal system performance (payload, throughput …) is no sufficient indicator.

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The effMFS project is divided into six work packages (WP) as follows for a period of 36 month.

The WP1 and WP2 include extensive pre-studies of state of the art and an overall roadmap for a successful settlement of the project.

The WP3 and WP4 handle approach and development of well-structured model of energy indicators (devices and processes) as well as efficiency investigations of conveyor systems.

Strategic operation and control arrangements to increase efficiency will be processed in WP5.

The WP6 will include realizations and validations of specific improvements (e.g. drive train, modes of operation) and tasks to discuss the elaborated overall standardized efficiency indicator-model and calculation methods within the scientific and industrial community.

3. ENERGY EFFICIENCY OF CONVEYOR SYSTEMS

Conveyor technology has been forming a widely spread standard element of intra-logistic systems for many years. Indeed, investigations were hardly done under the aspect of an increase of energy efficiency up to now. The characteristic actual energy consumption of these facilities is often unknown.

This main section illustrates the potentials and possibilities for increasing energy efficiency of conveyors. The effMFS project covers three different types of conveyors for standard boxes or trays with a payload up to 50kg. Results of two types of roller conveyor are detailed shown; one operated by drum motors; the other by an internal flat belt and one central motor.

3.1 Conveyor systems and investigations

A look to the detailed conveyor designs shows a complex optimization problem. The energy consumption of electronics (system power-supply, power converters, controllers), motors, drivetrain-components and the specific conveying elements itself must be considered. The mechanical components are buildup of many pulleys, tensioning devices and different flat and multi-ribbed belts (poly-V) for power transmission. Figure 2 shows general schemas of conveyors; a block diagram of the basic elements and a layout of a possible drivetrain.

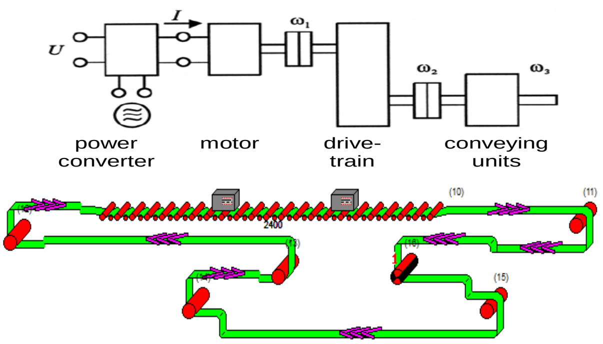

Figure 2. Schemas of roller conveyors

No information of the losses of the single components of the conveyors exists. First investigations focus on the share and range of these single losses.

Later, for the efficiency indicators relations to the single load, the number of units and velocity must be considered.

For that purpose, three test stands were installed at the Institute of Logistics Engineering. In general optimization potentials exist, by the basic decision of the conveyor design and by improvements of the carried out specific component-losses of the conveyor-types.

Figures 3 and 4 show two test rigs, both in a circular layout. Each rig is buildup of two identical conveyors and two auxiliary transfer units. There is the ability for multi measurement cycles fulfilled to improve the reliability of the results. Both conveyor types are able to convey “without traffic jam”, because of the possibility to stop the boxes on the track.

First conveyor test rig is installed with several drum motors (RC-DM), one for each section (figure 3). The power unit processes 24VDC.

The other test rig (figure 4) is buildup of conveyors operated by one asynchronous gear motor and one internal flat belt system (RC-FB) for all sections.

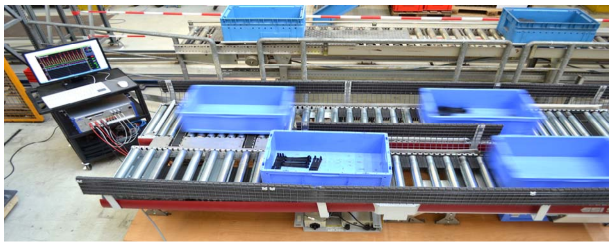

Figure 3. Roller conveyor - drum motors (RC-DM)

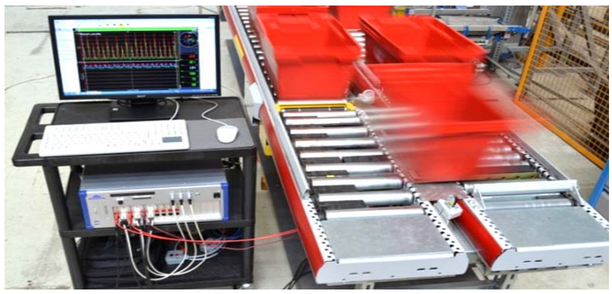

Figure 4. Roller conveyor – flat belt operated (RC-FB)

3.2 Detailed design of experiments

To be able to determine the specific potentials for conveyor design based improvements of energy efficiency all part losses have to be measured. Therefore, in a first task useful breakpoints were specified to separate the main assemblies.

To get results for interesting subunits and single elements, strip-down procedures are specified in a second task. The “Strip-Down” method is based on a successive following measuring series. Element by element is successively removed from the total unit. The losses of the elements can then be calculated from the comparative measuring results.

Examples therefore, roller section by roller section as well as single rollers and poly-V-belts for the transmission from roller to roller within one roller section.

Figure 5 shows the construction of the flat belt operated conveyor unit.

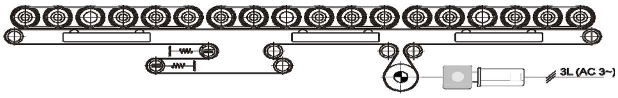

Figure 5. Layout of the flat belt operated conveyor

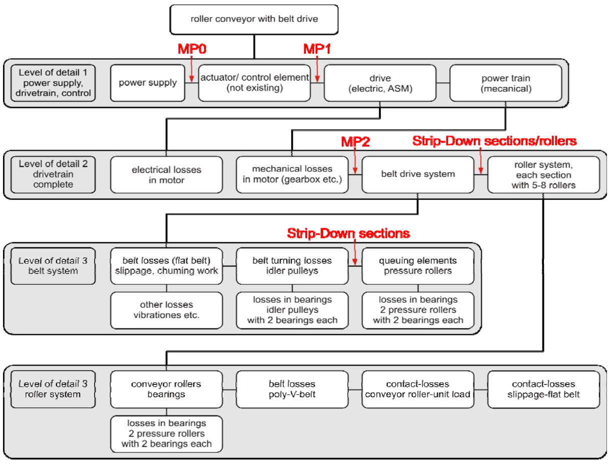

Figure 6. Schematic buildup and measuring points (RC-FB)

Figure 6 illustrates the schema of the specified measuring points (MP) and the strip-down tasks. This was processed in three different levels of detail. That allows a structured identification of all relevant losses, related to the basic assemblies (figure 2) or to single components. Partial losses of single components could be determined by means of theoretical investigations, literature studies or additional test stands if necessary.

More details of the measuring tasks (strip-down) for both conveyor systems are carried out at the results.

3.3 Detailed discussion of measurement tasks

This subsction deals with the specific measurement demands, devices and tasks.

Three sections follow focusing mechanical and electrical power measurement problems and realizations as well as a detailed discussion of the processed measuring series.

The mechanical power (figure 6, MP2) is determined with two different methods, both using the measured variables torque and angular speed.

On one hand, the torque is directly measured using an industrial torque transducer (M) (figure 7, right), on the other hand, the torque is determined via a combination of industrial force transducer and specific designed torque compensator ($F \cdot r$) (figure 7, left).

The angular speed (ω) information is provided in both cases by a standard speed-indicator.

These two setups are necessary to fit the different geometric boundary conditions of the test benches. An additional benefit is the possibility to validate all the involved components of the measuring chains (HW and SW). Meeting the specified measuring points (figure 6, MP2), for mechanical power, reconstructions at the conveyors had been designed and realized.

Electrical power measurement (figure 6, MP1) includes high by sophisticated demands depending on the realized power converter and motor installation.

The accurate determination of the electric power consumption could require very high sample rates for the data acquisition. There is the need to over sample all relevant frequencies (voltage and current) and calculate their share of power based on Fourier analysis.

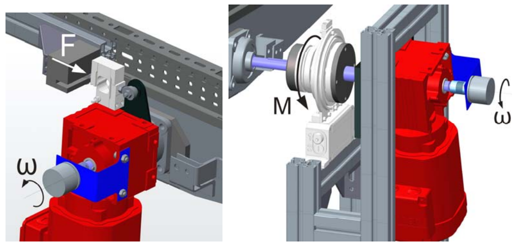

Figure 7. Measurement setups for mechanical power

Frequency converters have switching frequencies of e.g. 16 kHz. The high harmonics of the signal can form a substantial share of the total electrical power in the system. For the power calculation, all relevant harmonics of the signals have to be considered as particularly root-mean-square (RMS) values. The calculated values must be arithmetic average values (means) over several periods (times of oscillations).

A similar measuring problem is given in the VDI 4707 “Lifts energy efficiency” [2], where demands for the power measuring instruments are prescribed:

- Determination of 3-phase RMS power with a minimum of three values per second
- Consideration of harmonics caused by voltage of frequency converters
- Sufficient measuring range for acceleration and standby
- The RMS values must be processed while continuous data acquisition
- Recovered energy must be considered

The measurement equipment in use is an IPC-based universal measuring system from Dewetron®. It is perfectly suited for high-end flexible instrumentation, equipable with up to 16 modules. The current used configuration includes three high-voltage channels as well as three low-voltage modules extended with current clamps. The system allows sample rates up to 500 kS/s.

In addition, for the determination of the mechanical power other low-voltage channels are arranged (force, torque, speed).

For data recording, visualization as well as power calculation and data analysis the appropriate measuring software DeweSoft® is in use.

Test sequences are carried out based on the specified test- and measuring plan. It is necessary to meet most representing cycles.

The actual load of the whole conveyor is depending on the throughput (λ) in general. The considered specific parameters are the number of boxes (#), the current load (m) of the boxes as well as the conveyor velocity (v).

There is no clear definition available for the test cycles. Anyway, they must be specified considering the actual conveyor properties.

Both focused conveyors operate with fixed speed. Therefore, the available parameters to adjust throughput (λ) are number (#) and the load (m) of the boxes. The following table shows the structure of test sequences. Selected table elements in brackets (x) means that not all subtests are applicable.

Table 1. Structure of test sequence for parameters #, m

Number of boxes (#)	Load (%) of boxes (payload 50 kg)		
	0%	50%	100%
0	(x)	(x)	(x)
1	x	x	(x)
n	x	(x)	(x)

Data processing and interpretation is still a sophisticated task independent from the powerful test equipment. The reasons are the dynamic behavior of the total test benches. It is caused on one hand by stop and go operation on the other hand by the sub sequences of incoming and outgoing boxes at the conveyor sections. Other problems and limits are based on the strip-down aspects. Accordingly, there are high numbers of measurement and analysis tasks to carry out accurate cluster of values.

3.4 Power losses of conveyors – detailed results

As mentioned before, in focus of the investigations of the first project year were two roller conveyors of the three. The detailed investigation of the belt conveyor will follow in the second project year.

Roller conveyor operated by drum motors (RC-DM)

Meeting the basic structure of conveyor systems (figure 2) the RC-DM consists of the main components as shown in figure 8. The figure also illustrates the specific strip-down procedure as mentioned in chapter 3.2 in general. Each conveying segment is powered by one drum motor and includes 5-7 driven rollers. A cluster of drum motors (segments) is powered by one common control-unit. The power supply is realized as an AC/DC converter.

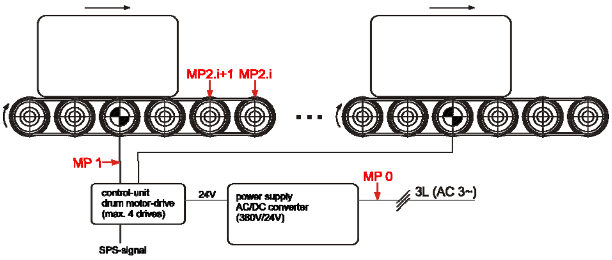

Figure 8. Schematic representation of RC-DM

The results of the investigations as discussed in section 3.2 are illustrated in figure 9. The quantified relative power losses of the components and some elements are figured out for a load of 25kg.

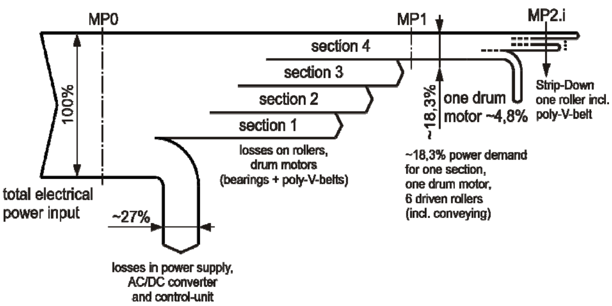

Figure 9. Power losses of RC-DM (load 25kg)

It is obvious, that 27% of the total electrical input is necessary to run the power supply and the control unit (electronically converters AC/DC and DC/DC). The rest of the input power (73%) is used to operate the conveying group of four segments. So, 18.3% is the share of one segment incl. the transportation of the load. The drum motor itself requests 4.8%.

As a specific result of the strip-down measurement procedure the share of the single rollers (including poly-V-belt) could be evaluated.

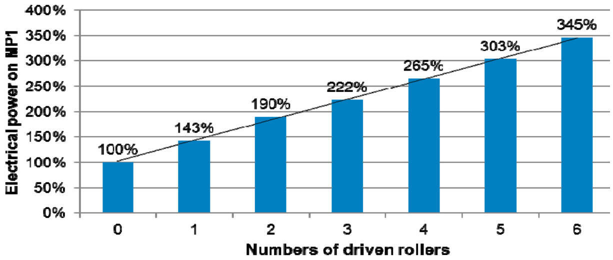

Figure 10. Power consumption of roller elements

The range of the needed power for a single roller is the one-digit watt range. It is obvious, that there is a linear dependence of power consumption between the numbers of driven rollers. Figure 10 spreads the results normalized to the value of the drum motor. The absolute values are private.

Roller conveyor - internal flat belt system (RC-FB)

Figure 11 illustrates the layout of the RC-FB consisting of the subunits: gear-motor, drivetrain (flat belt system) and the conveying roller sections. Based on the single speed operation there is no power supply unit to consider. In opposite to the RC-DM only a simple contactor is in use.

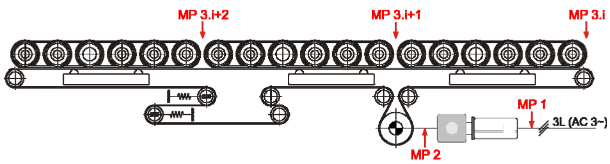

Figure 11. Schematic representation of RC-FB

Carrying out the adequate test sequences give the results for the RC-FB related Sankey-diagram of power losses (figure 12, load 25kg).

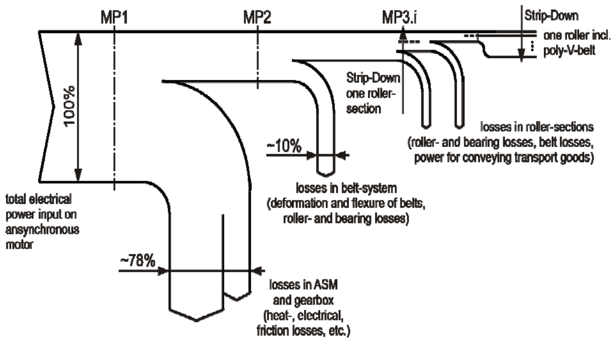

Figure 12. Power losses of RC-FB (load 25kg)

Results show that the used gear motor has a very bad overall efficiency. Depending on the load, there is an efficiency of 20-42%.

On one hand, this can be explained by the low efficiency of the worm drive of approx. 0.7-0.8 [3], which is a part of the gear motor. On the other hand, the asynchronous motor runs far below its nominal load, which means far outside its optimum efficiency range.

Here, the fact comes up that asynchronous motors of smaller nominal power have a lower efficiency ($\eta = f(Pn)$) [4] than motors of higher nominal power.

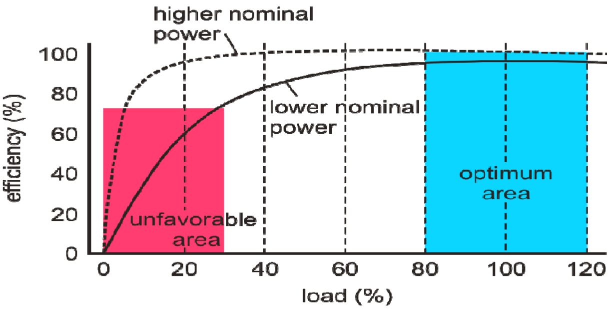

Figure 13. Efficiency of asynchronous motors [4]

In addition, we recognize an oversizing of the gear motor at the RC-FB test rig.

We find a similar situation at the RC-DM system for power supply and control units. Their efficiency depends on nominal power range and current load too.

3.5 Scientific findings

The carried out expertise (figures 9, 12, 13) indicates the saving potentials in context of construction units. Analyzing the results with a focus on the just above-mentioned RC-FB facts important findings are as follows. Of course, the motor sizing is to discuss under consideration of overall aspects. That means e.g. one motor-unit for a group of applications and system variants.

Figure 14 shows the share of life cycle costs of small-sized standard asynchronous motors in comparison to synchronous motors [5]. The figure does not include converters and gearboxes. Nevertheless, it is clearly recognizable that the predominant share of the costs of drives results for energy.

A consequent consideration of the share of lifecycle costs should affect future decisions about drive-system realizations. However, alternative drive technologies cause higher investment but should safe money in short time. An ROI calculation could be done for specific systems only.

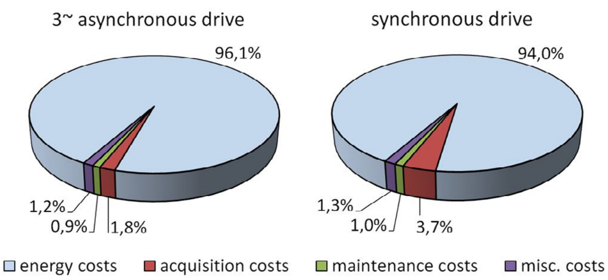

Figure 14. Life cycle costs for different motor types [5]

It is to aim to replace existing drives with new high-efficiency-drives. Additional discussions have to consider saving potentials in relation to optimized controlled operation modes. Application of frequency converters e.g. supports optimized speed, considering the current throughput-needs.

Clear energy-efficiency ratings in general need benchmark and indicator specifications, which are currently not available – compare [6]. That is another heavy work package of the effMFS research project. The next section illustrates an overall draft and some specifics for energy-efficiency-indicators of conveyors.

4. ENERGY EFFICIENCY INDICATORS (EEI)

Energy efficiency is an increasing by hot topic in general and in in-plant MFS too [1], as mentioned in the introduction. However, the provided information concerning energy efficiency and possible savings are not usable (insufficient statements). It is unknown how and under which conditions the respective MFS manufacturers determine their information of energy consumption or savings. This leads to an uncertainty in industry as well as by customers and manufacturers.

Soon it could be necessary for manufacturers to join the trend: What is about the energy efficiency and the depending lifecycle costs? Due to the fact of missing standards in determination of energy savings, the proposed information about the increase of the energy efficiency currently cannot be compared.

One important precondition to establish improvements (technology and sales) is the ability to compare performance under clear condition. This demands a standardized rating system fulfilling overall requirements of the problem in focus. There is the need to establish comprehensive models of energy efficiency indicators (EEI) for material flow systems (MFS). That has to include methods for calculation and measuring too.

Each standardized EEI-model has to be based on system requirements independent from used technology, actually deployed MFS and manufacturers.

The comprehensive approach of EEI-model was developed under consideration of classified system levels of material flow systems (MFS). Represented are different degrees of complexity of intra-logistic systems as well as depth of details in focus.

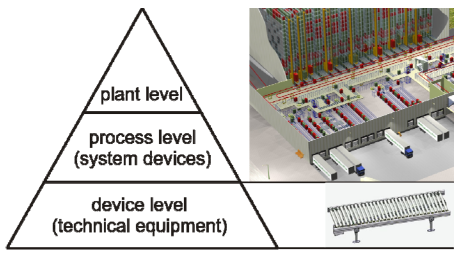

Figure 15. Levels of MFS and EEI

Our approach specifies three levels of MFS as shown in figure 15. The level structure is similar to the common levels of system automation: Enterprise Resource Planning (ERP), Manufacturing Execution System (MES) and Device/Unit. A conveyor system is an example for the device level. The process level includes groups of devices of the same or of more than one types, e.g. conveyor plus automated warehouse systems plus order picking units of a distribution center.

The plant level represents the overall facilities at the location but will not be addressed in this project.

At device level, the actual physical technology, components and elements of devices must be investigated to calculate EEI, e.g. conveyor systems, sorters, automatic storage and retrieval systems, etc.

A standardized representative operation cycle (ROC) is an important part of each EEI model. Figure 16 illustrates an example. ROC must be specified on common requirements of the type of addressed devices/processes. A single evaluation at nominal load/operation is never adequate for real life conditions. So, energy efficiency indicators are introduced under consideration of general energy efficiency definition, according to EU-directive 2006/32/EC [7].

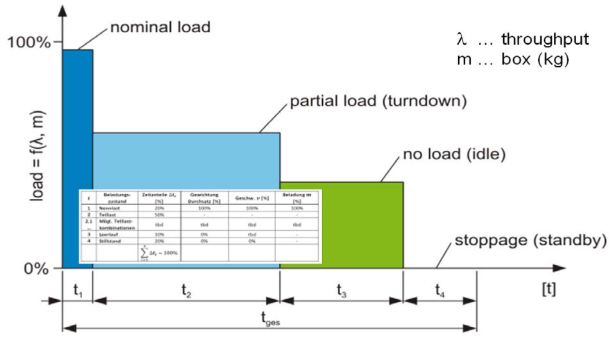

Figure 16. Example - representative operation cycle (ROC)

Several approaches are already under discussion and validation. An EEI example is described as follows.

An EEI conveyor Example _: The specification leads to the equation based on the definition as follows. Definition: Energy consumption (E) of conveyors (C) for one load unit (LU) for a distance of one meter (s). The related ROC is roughly illustrated in figure 16.

$$E_{C/(s,LU)} = \sum_{i=1}^{4} E_i = \sum_{i=1}^{4} P_{i/(s,LU)} \cdot t_i ; \; i ... load = f(\lambda, m) \quad (1)$$

Energy efficiency indicator models for process level (EEI_Process) have to consider process specific requirements and operation cycles. The calculation has been based on the determined EEI of included devices. The approach of the process level model is currently under construction and therefore not addressed.

5. CONCLUSION

The results of the first of three “effMFS” project years show great promise.

The carried out power consumption details, of both investigated conveyors (RC-DM, RC-FB), give clear information about the saving potentials (figure 9 and 12). Higher investment affected by design decisions for more efficient components (e.g. gear motors) could be recovered soon (figure 13 and 14). A comparison with a third common conveyor type (belt conveyor) will follow. Further project tasks will include realizations of improvements with high efficiency potentials too, in relation to specific conveyor types.

A systematic approach for an energy efficiency indicator model (EEI-model) is carried out, classified for device and process level of MFS (figure 15). First device EEI (for conveyors) are specified as well as the needed representative operation cycles (ROC, figure 16). The specification of a comprehensive EEI-model for typical overall MFS will be in focus for the next months. That has to include subtask dialing with clear boundary conditions, standardized ROC and measuring as well as calculation methods.

ACKNOWLEDGMENT

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ЕНЕРГЕТСКА ЕФИКАСНОСТ СИСТЕМА ТОКОВА МАТЕРИЈАЛА

Норберт Хафнер, Флориан Лотерсбергер

Аутоматизовани системи токова материјала се све више користе у многим гранама индустрије. Енергетска ефикасност ових система постаје све значајнија. Након уводног дела укратко ће бити приказани основни елементи енергетске ефикасности система токова материјала. У трећем поглављу описане су детаљне студије ефикасности различитих типова транспортера. Резултати у оквиру овог истраживачког пројекта су верификовани мерењима и процењене су могућности побољшања система. Да би се повећала свукупна енергетска ефикасност система токова материјала неопходно је имати индикаторе стандарда ефикасности који задовољавају реалне услове рада. Дискусија везана за енергетску ефикасност приказана је у поглављу 4 укључујући и одговарајуће примере за транспортере. У закључку су сумирани резулти и дат је преглед будућег истраживања.