Possible Ways of Measuring and Calculating Waste Heat from a Machine Diagnostic Approach

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***Abstract*— Utilization of waste heat is one of the most important parts of energy efficiency. There are several possibilities for this calculation, in this thesis we partly relied on the theory of similarity. The target of using waste heat is to achieve the best possible system efficiency within a complex system. Measurement of the drive motor, torque converter, inverter, battery and shaft connection must be examined together. We summarize the results of this work.**

Keywords*— *The similarity theory, flow processes, temperature transfer, modeling processes, thermal conductivity coefficient, thermography, overheating, heating process

I. Introduction

Similarity theory is a widely [1-36] applied branch representing a separate scientific field. It is easily and quickly spread in simpler applications, e.g. in the fields of geometry, fluid flow, heat transfer processes, heat transfer modeling. The possibilities of transport processes that can be modeled with each other clearly show this relationship.

A. Interpretation, model creation

The model is a simplified copy of reality that behaves like reality from the point of view of the examined phenomenon and the defined target within it [1].

Ways to create models [2]:

- Given in the usual way, using approximations.
- Habits, usual models E.g. Mathematical models, static calculations
- Routine tasks, engineering response from the offered or known options.
- Based on a lot of experience, intuitively.
- It is not a routine task, but a new problem to be solved.
- Many times the proven and usual models are used possibly incorrectly or incorrectly.

B. Basic principles for model creation

The model is also determined by the test objective. The purpose of the model is to make calculations regarding the behavior of the model by knowing and using the laws. Based on the results of the calculations, we can achieve an expansion of knowledge about reality [3].

C. •The basic issue of model creation is abstraction

Based on our created models, we can gain new information about the world, but the results obtained in this way must always be compared with reality and the set goal, and as a result, it can only be decided whether the created model is correct [4].

The model depicts the prevailing order in reality, it does not deal with the contingencies of the world [5].

Among the order-determining factors, only those corresponding to the purpose of the investigation are taken into account.

•There may or may not be approximations in the calculations performed on the created model, either in the written equations or in their solution [6].

D. Methods of model creation

- Analytically calcula ble, exact models.
- The error of the model is within the allowable error defined by the test objective.
- Error estimation based on experience.
- The role of experience is decisive.
- They can be used well for parameter testing.

E. Approximate models

•In the case of very complex phenomena, it may become necessary to use models that present the phenomenon but do not approximate it with the accuracy required for the purpose [7].

The principle of gradual approximation (creating more and better models) [8-12].

Complex solution (experimental, mental models, e.g. in research tasks)

F. Modeling To create an experimental model

- Parameter testing.
- Numerically solvable models.
- The most complex modeling methods.
- It cannot be used for the general solution of complex engineering tasks
- Good additions to engineering activities, tools in the hands of the engineer.
- The solution is performed by a computer, but the results must be interpreted by a human!
- Steps of model creation.
- Observation of reality.
- Selecting the aspect.
- Main features:
- Creation of the model.
- Complex reality, simple model.

G. •Interpretation of prediction based on the model into a phenomenon

- The model must be operated.
- Experimental verification of prediction.
- Model experiment.
- Application of the model within the validity limit.
- Further development of the model, extension of validity limits.
- Reality, model, conclusion.

II. Basic concept of similarity theory

Due to the possibilities of the analytical method, the experiment is of great importance in the study of heat transfer processes. When designing an experiment, two goals can usually be set [13-18].

A detailed study of the investigated phenomenon.

And let's get the data to calculate other phenomena related to the one being studied.

However, the results of individual experiments can only be extended by the so-called can be for similar phenomena. Consequently, depending on the purpose of the experiment, it is already necessary to know the following:

What quantities must be measured during the experiment?

How should the results of the experiment be processed?

What phenomena are similar to the investigated process?

The answer to these three questions is contained in the three theorems of the theory of similarity.

III. Concept and definition of similarity

The theory of similarity is nothing more than the teaching of similar phenomena. We first encounter the concept of similarity in geometry, and we "borrow" the expression of similarity itself from there [19-25].

Eg: in the case of geometrically similar shapes.

The concept of similarity can be extended to any physical phenomena. Thus, we can talk about the similarity of the movements of two fluid flows, which create movements similar to each other, i.e. dynamic similarity, and we can talk about the similarity of temperatures and heat flows, i.e. thermal similarity.

First of all, in relation to physical phenomena, the concept of similarity can only be applied to phenomena of the same nature, that is, to those that are qualitatively the same and whose analytical description is the same in terms of shape, but different in terms of physical content, then these phenomena are called analogous processes [26-30].

A. Definition (similar phenomena)

Similar are the phenomena that are characterized by a constant ratio of identical quantities corresponding to each other.

B. Definition (similarity constants): k

The ratio of the analog parameters of the model and the large process/phenomenon/equipment is constant. Ex: l', l=áll. (length ratio is constant)

C. Definition (similarity invariants): i

The ratio of analog parameter pairs of the model and the large process/phenomenon/equipment is constant. E.g. (l', ρ'), (l, ρ)=áll.(length, density parameter pair ratio is constant).

- Conditions ensuring similarity
- Identity of phenomena
- If two phenomena are identical, they are similar
- Geometric similarity

If two processes/equipment are geometrically similar, they are similar according to similarity theory.

Physical similarity (scale)

If the ratio of physical quantities in two processes is constant, then the two processes are similar according to the similarity theory. Ex: ρ', ρ=áll., (ratio of densities).

D. Temporal similarity

If two phenomena or processes show a temporal similarity based on the time scale that takes place in them, then the two phenomena, processes, and the similarity are theoretically similar. E.g.: t', t.

The similarity of the clarity conditions is satisfied.

The similarity of the initial and boundary conditions is fulfilled.

The similarity of expressions without dimension (unit of measurement) is fulfilled.

Example:

These conditions can be formulated using the example of a similar flow of real fluids in industrial pipelines and a small model:

The flow of fluids in the tested pipeline and in the model is similar if the ratio of different dimensionless complexes = different physical quantities is constant.

Definition (dimensionless criterion):

If the similarity, dimensionless complexes are obtained by transforming the differential equations describing the process, then these are called dimensionless criteria.

Theorem (Newton's law):

If the systems are similar, that is, if two systems are similar, then there are always dimensionless complexes in them that are identical to the corresponding points of the given systems.

Theorem (Kirpitsov's law):

Two phenomena/processes/systems are similar if and only if they can be described with the same (type of) differential equation and in the case of which the similarity of the clarity conditions is also fulfilled.

So this provides a necessary and sufficient condition for the similarity of two systems.

IV. Modeling Requests

A. *Modeling steps*

A model-as a specific form of cognition-represents the investigated object more simply, materially or conceptually. There is always a precisely defined correspondence between the object and the model. The model enables the acquisition of new knowledge in the cognitive process and research; it can appear as an intermediate connecting between individual theoretical systems, theory and practice, theory and reality [31-33].

B. *Models are usually classified according to their structure*

- Material models
- Geometric models
- Physical models
- Object-mathematical models
- Cybernetic models
- Replica models
- Signal models
- Mixed models

In considering our research and applying similarity theory, each type of model must be used because there is no ideal choice. The extent of the drive chain (geometric model), its material (material model), movement conditions (physical, material-mathematical model), the operation of the analysis software (cybernetic model), recorded thermal images, function transformations (image model, signal model and their combination) must be taken into account, mixed model).

The model is the device that realizes a phenomenon similar to the original. The similarity theory dictates the conditions under which the similarity between the model and the original can be ensured. Knowing this, the similarity between the model and the original. Knowing this, the data measured on the model can be transferred to the original equipment.

Knowing the rules of modeling makes it possible not only to change the scale, but also to use a working environment different from the original, and even to replace one group of phenomena with another. Thus, it is possible, for example, to study heat flow in a water model, to investigate the diffusion process with an energy flow caused by temperature inhomogeneity, to solve complex aerodynamic problems in an electrical network model.

V. A Possible Way of Utilizing Waste Heat

Thermocouples are basically well-known devices. The emphasis is more on how to identify and use the stress created by the temperature difference of different materials.

For the correct application of thermocouples, the electronic physics essence of the contact potential must be known. A contact potential or thermopotential occurs at the contact surface of two different metals. This is related to the atomic structure of metals. The resulting charge separation force depends on the kinetic energy of the electrons of the two metals. This force is greater, the greater the difference between the kinetic energies. Since the magnitude of the kinetic energies of individual metals and thus their difference also increases as the temperature increases as a result of the thermal motion of the molecules, the contact potential is suitable for measuring temperature.

After the charge separation, an electric field strength occurs, which means an electric attractive force. As a result, the charge separation force and the electric attractive force are balanced.

The size of the contact potential can be determined using the energy levels of the two metals using Fermi-Dirac statistics. In the case of technical applications, these calculations are not absolutely necessary, it may be sufficient to write them down through modeling, but it is not always necessary to proceed in this way, especially considering the complexity of the task.

By increasing the temperature of the contact surface of the metals, the difference between the energies of the electrons of the two metals increases and the contact potential increases as a result of heat movement [34-36].

VI. Thermal Radiation

About electromagnetic radiation: The propagation of heat in this form does not require a medium in the traditional sense: The energy is transmitted by the photon gas that propagates according to the laws of wave motion, which is called electromagnetic radiation. The importance of radiative heat transfer is not only given by the fact that most of the useful amount of energy comes from solar radiation, but also by the fact that in the case of significant temperature differences between bodies, the three basic forms of heat transfer (conduction, convection, radiation) become the decisive.

All tests emit electromagnetic radiation. At room temperature, its energy is mostly negligible. As the temperature of the body increases, the energy content increases, then the dominant wavelength of electromagnetic radiation decreases and shifts from the visible infrared range to the ultraviolet wavelength range.

VII. THERMO MANAGEMENT AND RESULTS

Based on the thermographic diagrams of the following chapters, a concept must be deduced that can solve the loss map assigned to the vehicle's driving cycle and the waste heat utilization process. The problem with the measurement is that it was performed at a low load and not in the full load range, so you have to deal with significantly higher temperature conditions.

The previously mentioned winding loss and other loss components must be treated together with the driving cycle of the vehicle.

In earlier stages of the research, the basic concept of the torque-current limit was mentioned:

The purpose of this process is to ensure that the selected current limit is always closest to the section of the load characteristic curve, i.e. the motor does not fall out of the optimal efficiency range.

This has several influencing factors, such as temperature. The heating of the engine significantly shifts the optimum points in terms of the torque-angular velocity segments of the shifting processes. During the successive back-and-forth changes, the engine goes through a cooling or heating process, so a preliminary calculation does not necessarily lead to a result for starting the next intervention.

The purpose of laboratory measurements is to get to know the heating conditions of the machine system before road measurements take place.

The following pictures are made for clutch heating in order to show how much heat loss to expect.

During the measurement, the thermal camera was set to Fahrenheit, so you can see the Celsius value under the images.

During this measurement, the shaft coupling has not yet reached its maximum temperature.

Shaft coupling heat running (heat run test, shaft misalignment, because of rotary knock and friction)

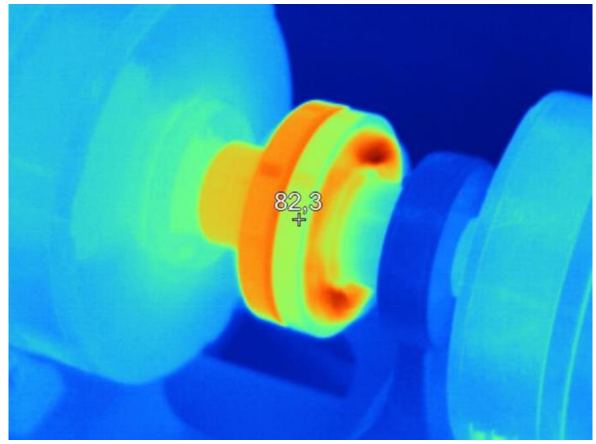

Fig. 1. Shaft coupling heat running : 82.3°F= 27.94444°C

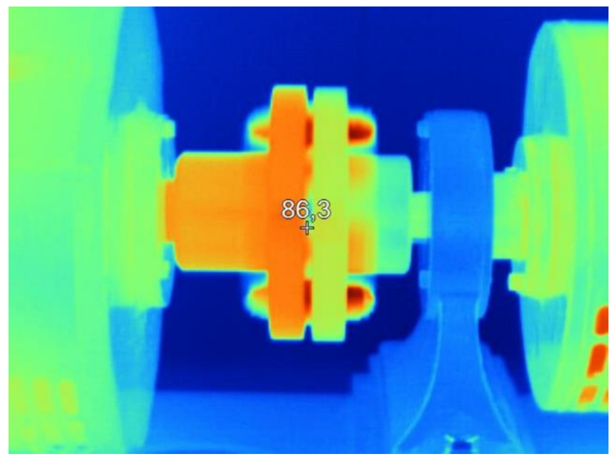

Fig. 2. Shaft coupling heat running: 86.3°F= 30.16667°C

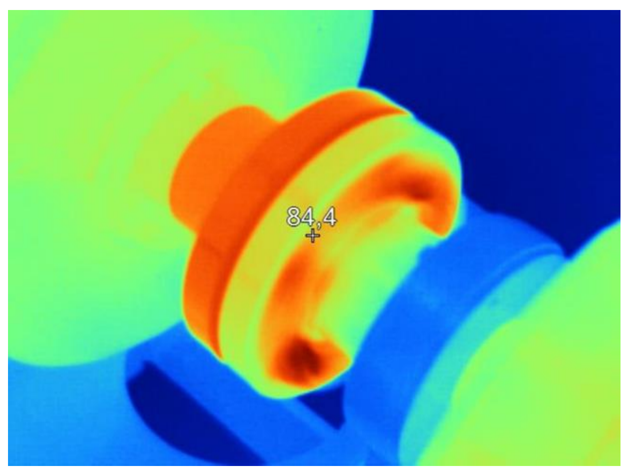

Fig. 3. Shaft coupling heat running : 84.4°F= 29.11111°C

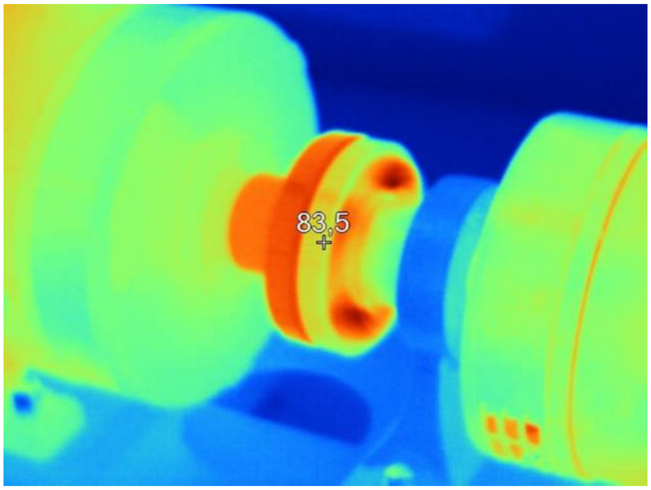

Fig. 4. Shaft coupling heat running: 83.5°F= 28.61111°C

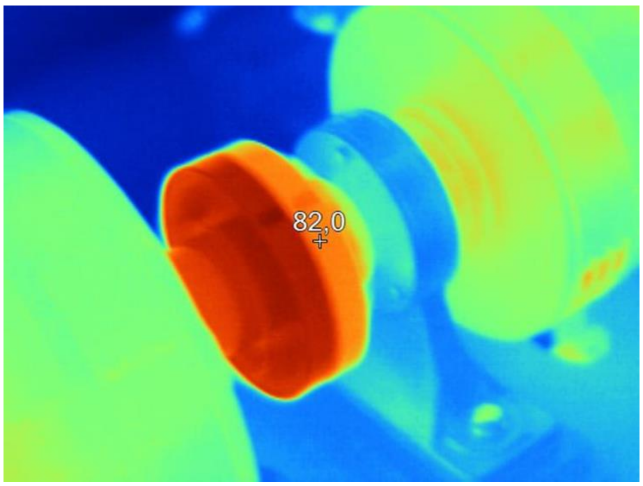

Fig. 5. Shaft coupling heat running: 82°F= 27.77778°C, cooling back.

Based on the example of winding loss, this method can only be used as a basis here.

Reason: The load state of the motor that ensures the vehicle's progress is constantly changing and waste energy must be generated from a process taking place over time.

Application of definite integral:

If we want to define the curve of a continuous function f (x) interpreted in the interval [a,b], the ordinate sections belonging to the boundary points a and b, and the area delimited by the x-axis (sign), then the function taken from a to b is defined integral must be formed:

$$T = \int_a^b f(x)dx$$

Signed area means that (for a<b) the area above the x-axis has a positive sign and the area below the x-axis has a negative sign.

A. *Utilization of coil loss based on drive cycle*

All factors affecting the route must be taken into account. Not only the engine and drivetrain losses, but the factors affecting the entire vehicle movement.

Road influencing factors

- number of lanes
- entry and exit points of the measurement area
- road markings
- road geometry
- proper sensor setting
- influencing effect of road structure
- sensor conditions and disturbing signals
- volume of traffic
- traffic composition
- traffic speed
- levels of congestion
- number of lane changes
- active or inactive traffic control
- weather conditions that affect public transport
- incident and road construction works en route
- vehicle parameters and data
- losses incurred in accordance with this
- changes in the number of passengers
- drive cycle recording

Calculation of coil loss based on line resistance:

$$\frac{R_{warm}}{R_{cold}} = \frac{235 + T_{warm}}{235 + T_{cold}}$$

This basic formula is calculated cyl-wise.

It is determined not only by the winding loss, but also by the temperature conditions represented by the iron loss and the insulation system of the motor and resulting friction.

The heat map of the motor was calculated according to the manufacturer's data.

CONCLUSION

The application of the best possible measuring cards to be prioritized as a suggestion for further development, in order to suit the signal processing as much as possible.

For the research, prepare a device for laboratory conditions that measures the external temperature distribution with the help of thermal cameras.

At least as many temperature sensors must be placed in the finished vehicle, which shows how much heat loss is generated in different parts of the drive chain.

The heating test also includes what kind of cooling the battery unit has, how the cooling can be regulated in such a way that it does not cause overheating and can also support thermal management.

The current proposals are only a snapshot of the current phase, as the work progresses, new and better solutions are always created.

Measurement methods need continuous development. Mapping of the driving cycle in laboratory conditions compared to the operation of a real vehicle.

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