CV-joint Effeciency

Report 87100

Forschungsgesellschaft Kraftfahrwesen mbH Aachen
Acoustics Department

Final Report

CV-joint efficiciency

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1 Introduction

Within the development process of the automotive industry the reduction of fuel consumption is a major issue, in particular regarding costs and environmental pollution. By decreasing the external driving resistances both the engine and the gearbox have to be analysed and improved. The efficiency of these components has achieved a high level, therefore it is necessary to continue the optimisation process of specific powertrain components.

Within this project, the efficiency factor of CV-joints shall be determined by test bench measurements. Due to the fact, that the efficiency factor of CV-Joints has high levels (more than 96%), a high precision of measurements is necessary. The accuracy of conventional testing methods is insufficient. In order to determine the CV-joint efficiency with an economically justifiable effort, the “Insititut für Kraftfahrzeuge” (ika) and the “Forschungsgesellschaft Kraftfahrwesen mbH Aachen” (fka) developed an own method as well as a special test bench. Thereby the degree of efficiency can be determined in an adequate way with acceptable effort of measurements. For this purpose the efficiency factor will be evaluated, based on the thermal measurement of the CV-joints power loss.

Within the help of this measuring method the efficiency of a Thomson coupling and a standard ball joint will be determined.

2 Theoretical foundations of the efficiency measurement

The CV-joints efficiency is very high (more than 96%) in a wide range of operating points. Therefore a high-precision method, based on measuring the thermal dissipation loss, was developed at ika / fka.

Standard methods regarding the determination of the degree of efficiency for mechanical components, which have been used so far, like

- Input and output torque measurements by using strain gauges
- Self-aligning bearing of gearboxes
- Mechanical distortion
- Electrical distortion
- Direct measurement of the dissipated thermal losses

do not work in this case due to several disadvantages (M. Helbing, 7. Aachener Kolloquium Fahrzeug- und Motorentechnik, 1998).

The general degree of efficiency (η) is determined by the relation between input power (P_{zu}) and output power (P_{ab}).

$$\eta = \frac{P_{ab}}{P_{zu}} \qquad \text{Eq. 2-1}$$

The energy balance of a CV-joint is illustrated in Fig. 2-1. The output power P_{ab} results from the difference between input power P_{zu} and the dissipation power P_v.

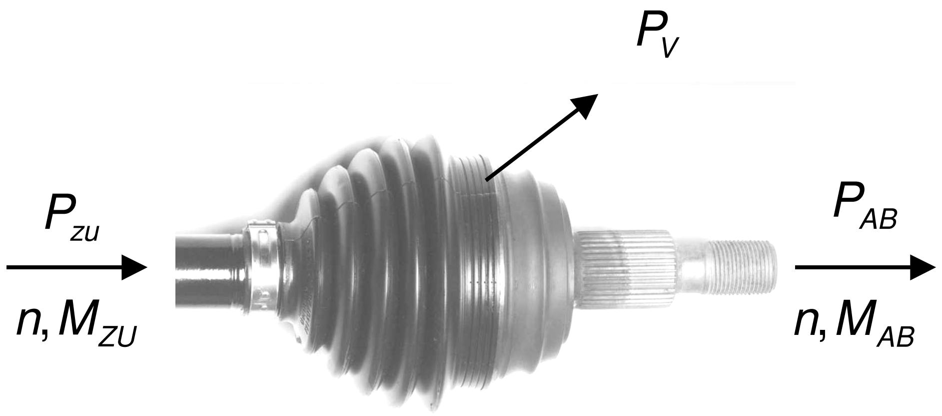

Fig. 2-1: Power balance of a CV-joint

Therefore the formula for the efficiency is:

$$\eta = \frac{P_{zu} - P_v}{P_{zu}} \quad \textit{resp.} \quad \eta = \frac{P_{ab}}{P_{ab} + P_v} \qquad \text{Eq. 2-2}$$

Based on the equitations Eq. 2-1 and Eq. 2-2 it is evident, that the efficiency can be determined in two different ways. One way is to measure the input power, the output power and the power loss (method **A**). Another way is to measure the input power and the output power (method **B**).

The method to determine the efficiency, which is used for this project, rests on measuring the input power, the output power and the power loss. Regarding the error analysis of the different methods, the advantages of the ika / fka method are illustrated in Fig 2-2.

A

Determination of power loss and input power (output power)

$$\eta = \frac{P_{zu} - P_v}{P_{zu}}$$

relative total error

$$\frac{\Delta\eta}{\eta} = \left[\left|\frac{\Delta P_v}{P_v}\right| + \left|\frac{\Delta P_{zu}}{P_{zu}}\right|\right] \cdot \left(\frac{1}{\eta} - 1\right)$$

B

Detremination of input and output Power

$$\eta = \frac{P_{ab}}{P_{zu}}$$

relative total error

$$\frac{\Delta\eta}{\eta} = \left|\frac{\Delta P_{ab}}{P_{ab}}\right| + \left|\frac{\Delta P_{zu}}{P_{zu}}\right|$$

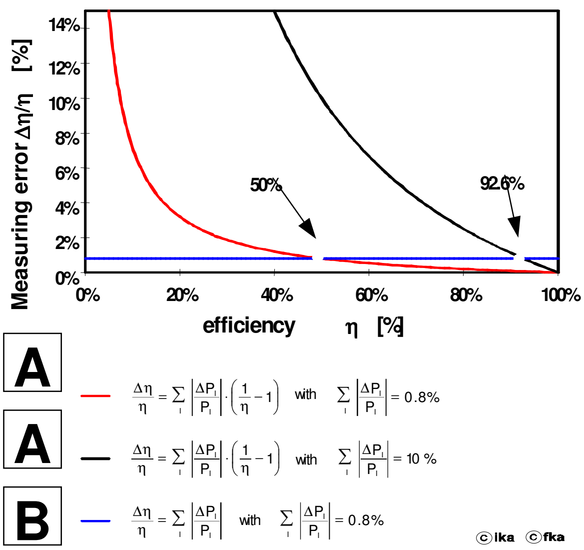

Fig. 2-2: Error analysis of the different measuring methods

Fig 2-2 shows the comparison of both methods concerning the theoretic achievable total measurement accuracy / relative total error (Δη/η) with reference to the single accuracy. Regarding the error analysis the method of the standard error accumulation is used.

The relative total error Δη/η of the measurement from both the input and the output power is equal to the sum of the percentage single errors $\Delta P_{ab}/P_{ab}$ and $\Delta P_{zu}/P_{zu}$. The achievable accuracy of the efficiency, using the input power or rather the output power and the power loss, depends on the efficiency of the system (i.e. CV-joint).

The valid formula for this measurement method is:

$$\frac{\Delta\eta}{\eta} = \sum_i \left|\frac{\Delta P_i}{P_i}\right| \cdot \left(\frac{1}{\eta} - 1\right) \qquad \text{Eq. 2-3}$$

This means, that for $\eta \to 1$ the value of the relative total error of efficiency tends towards zero.

The curve progression of the function $\Delta\eta/\eta$ depending on the system efficiency for both measurement methods is shown on the right hand side in figure 2-2. Both methods of measurement are based on the same single error $\Delta P_i/P_i = 0.8\ \%$. Additional the ika / fka method **A** - determination of the power loss - is based on an assumption of a high sum error ($\Sigma\Delta P_i/P_i = 10\%$).

It is stated, that for system efficiencies higher than 50% the measure principle method **A** is more accurate than the method **B,** regarding both curves with the same sum errors. With $\eta \geq 95\ \%$ ($\Sigma\Delta P_i/P_i = 0.8\ \%$) only an error of e.g. $\Delta\eta/\eta \leq 0.04\ \%$ is calculated. In case of a much higher sum error of 10% the obtained relative total error, when using the measure principle of method A, has lower values at higher system efficiencies ($\eta \geq 92.6\ \%$.) This is better than the achievable values of method B. Based on a high sum error ($\Sigma\Delta P_i/P_i = 10\ \%$) method A achieves an efficiency error of only $\Delta\eta/\eta \leq 0.05\ \%$ concerning system efficiencies (CV-joints) above 99,5 %.

3 Description of the testing method

A mechanical system like a CV-joint, that runs with a constant bending angle and a constant torque, is generating power losses (P_v) (Fig. 3-1).

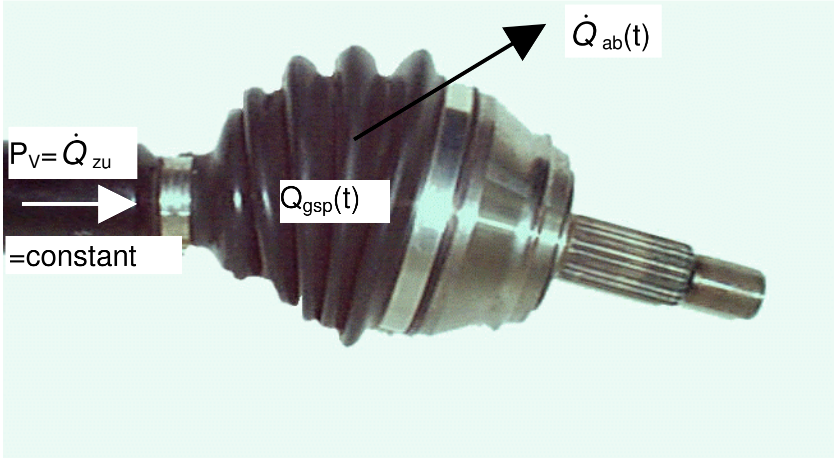

Fig 3-1: CV-joint as a non-insulated thermal store with constant heat input

Based on the assumption, that CV-joints are predominantly made of metal and that they are not thermally insulated, the power loss of this thermal energy storage is dissipated completely as thermal energy. In the testing routine of this project the CV-joints are supplied with constant thermal power under constant operating conditions (torque, speed and bending angle).

Due to the missing insulation, the CV-joint stores and also dissipates thermal energy to the environment. On the one hand the thermal dissipation depends on the storage level, and on the other hand on the thermal inflow. A constant thermal inflow induces a balance (Eq. 3-1) between the thermal inflow and the dissipated thermal power after the adjusting time. At this point the storing process is finished.

$$P_V = \dot{Q}_{zu} = \dot{Q}_{ab} \qquad \text{Eq. 3-1}$$

The thermal storage level is detected by the temperature gradients of the thermal store (θ_G), its environment (θ_U) and the temperature difference of both.

A typical heating-up curve of a not insulated thermal store (CV-joint with constant heat inflow) is shown in Fig. 3-2. It is pointed up, that the temperature difference reaches a steady state value $\Delta\theta_{stat,}$ when running at a constant operating point. At this time the thermal storage capacity has achieved its maximum value.

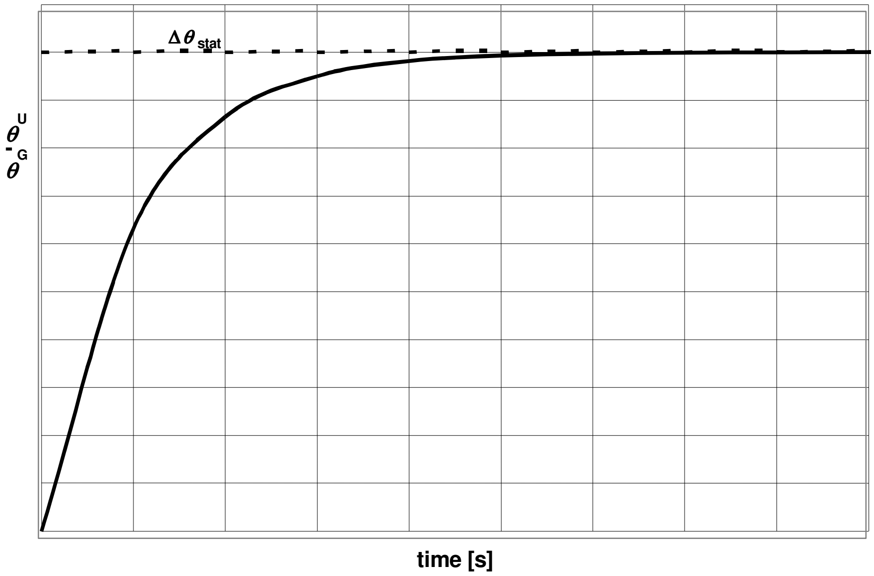

Fig 3-2: Typical heating-up curve of a not insulated thermal store with constant heat inflow

The temperature difference between the thermal store and its environment is used to determine the dissipated thermal flow of the CV-joint. In order to calculate the dissipated thermal power at the steady state temperature difference, the value of thermal power transfer between the thermal storage and the environment is needed. At this point the system setup is changed (Fig. 3-1) in order to determine this value. The thermal power inflow will be stopped by setting the torque and the bending angle to zero and the shaft speed is kept at a constant level. The thermal power balance of this setting is illustrated in Fig. 3-3.

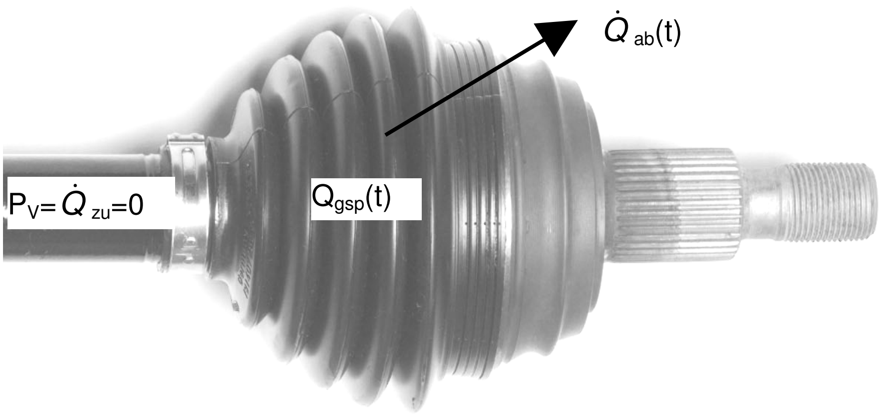

Fig. 3-3: CV-joint as a thermal storage without insulation and thermal power inflow

Without the thermal power inflow the cooling-down phase starts. The corresponding temperature curve is shown in Fig. 3-4.

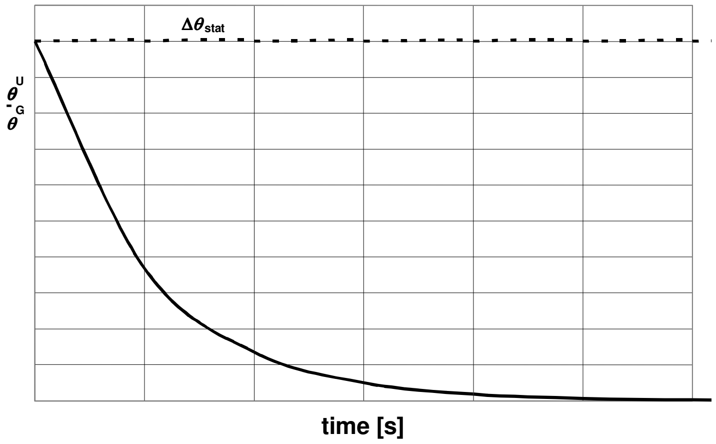

Figure 3-4: Typical cooling-down curve of a thermal store without thermal insulation

The dissipated thermal power is calculated by the thermal power transfer and the steady state temperature of the thermal store „CV-joint“. This is on par with the thermal power inflow, which is the power loss of the CV-joint. Finally the CV-joint efficiency is calculated by the power loss and the mechanical power input, given by speed and torque at this operating point (Eq. 3-2).

$$\eta = \frac{P_{An} - P_V}{P_{An}} \qquad \text{Eq. 3-2}$$

It has to be considered, that the thermal power of the joint can be dissipated by

- heat conduction
- heat radiation and
- convection

as shown in Fig. 3-5.

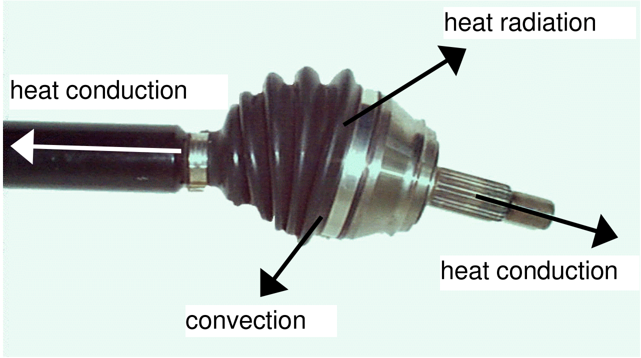

Fig. 3-5: Different ways of heat transmission

The formulation “convection” is selected for the determination of the thermal power transfer of the CV-joints to its environment. This proceeding is based on using the cool-down curve and the separated insulation of the CV-joints by materials with a low thermal conductance. The heat transfer, as a result of convection and thermal radiation, is calculated by the temperature difference between the CV-joint and the environment. The CV-joint is connected to the test bench with wooden flanges, realizing the thermal insulation to the test bench shafts. Furthermore a homogeneous temperature distribution of the CV-joint is assumed, based on the homogeneous material distribution and the high heat conductivity of metal materials. It is also required, that the temperature of the environment is nearly constant during the analysis. This applied method for efficiency analysis is validated by extensive investigations and also verified on its reproducibility in several tests at ika / fka.

The determination of the efficiency of one and the same joint under identical operating conditions on different days induces a maximum deviation of 0,01%. The following error calculation affirms this good results with a maximum deviation of ±0,05%. This implies, that the method achieves a sufficient accuracy for efficiency testing of CV-joints.

Due to a high overall efficiency of CV-joints and only small differences in efficiency, caused by the use of different greases or different joint types, the accuracy of the measurement must be very high. The verification of the achievable accuracy of the ika / fka measuring method will be rated in the following, regarding the single error sources and their influences on the overall accuracy of the efficiency.

As mentioned before (Fig. 2-2) the ika / fka efficiency method has the highest accuracy with the smallest relative error. For example, the relative total error is < 0.8%, based on a total error of 10% for CV-joint efficiencies higher than 92.6%. The accuracy of standard measuring instruments is much higher than 10%. This results in a higher accuracy . These aspects are illustrated in the following error calculation.

The first step is the identification of the maximum possible error of each measurement device. The relevant measured parameters, their maximum errors and their resulting deviation of the total efficiency are shown in Fig. 3-6.

input value	inaccuracy of the input value	deviation of total efficiency $\Delta\eta$
temperature fixed joint	± 1.55 %	0.0096 %
temperature enviroment	± 0.1 %	0.0003 %
torque / speed	je ± 0.2 %	0.0345 %
spec. thermal capacity	+ 1 %	0.0064 %
mass	± 0.1 %	0.0006 %

Fig. 3-6: Single error of the efficiency measuring method

Thus the total error of the measuring chain (sum of the single errors) has a value << 4 % (chapter 2). All values are determined sequentially, not parallel. Therefore the error of one single value is not increased by sequenced steps.

The influence of the single error of each measurement device on the determined overall efficiency value is illustrated in Fig. 3-7. For the evaluation procedure all input variables of the program have to be changed according to the determined values before. The maximum influence on the total CV-joint efficiency (0.0345%) is characterized by speed and torque. Both values can measured with a deviation of max +/- 0.2%. In this context the highest deviation (+/- 1.55%, joint temperature) results in a measurement uncertainty of max. 0.0096%.

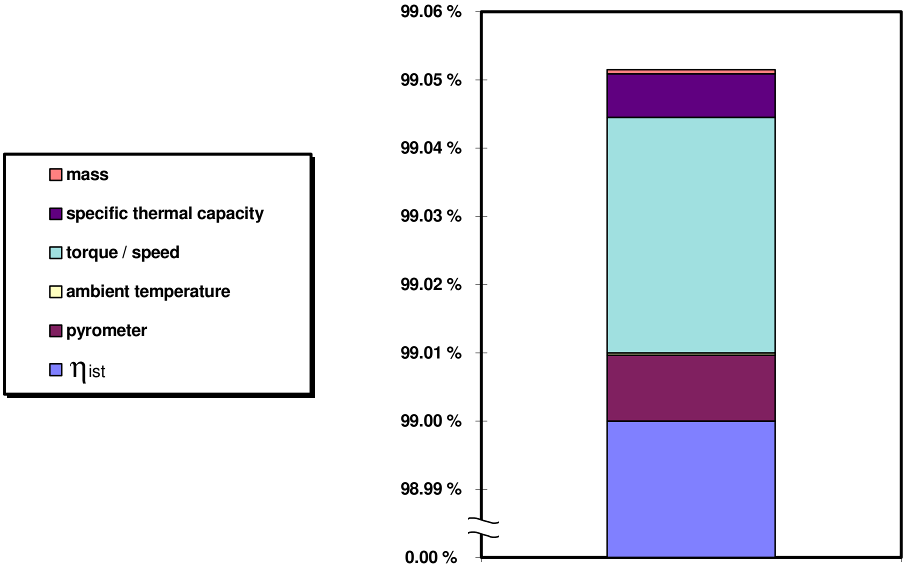

Fig. 3-7: Error values of CV-joint efficiency measurement

A measured efficiency of 99.05% is determined based on a real efficiency of 99% added with all possible errors. The relative error $(\Delta\eta/\eta)$ of the ika / fka efficiency measuring method is lower than 0.05 %, hence the accuracy of the method is qualified for CV-joint efficiency measurements.

4 Testbench setup

The ika / fka CV-joint test bench, developed for efficiency and NVH – investigations of CV-joints, is illustrated schematically in Fig. 4-1.

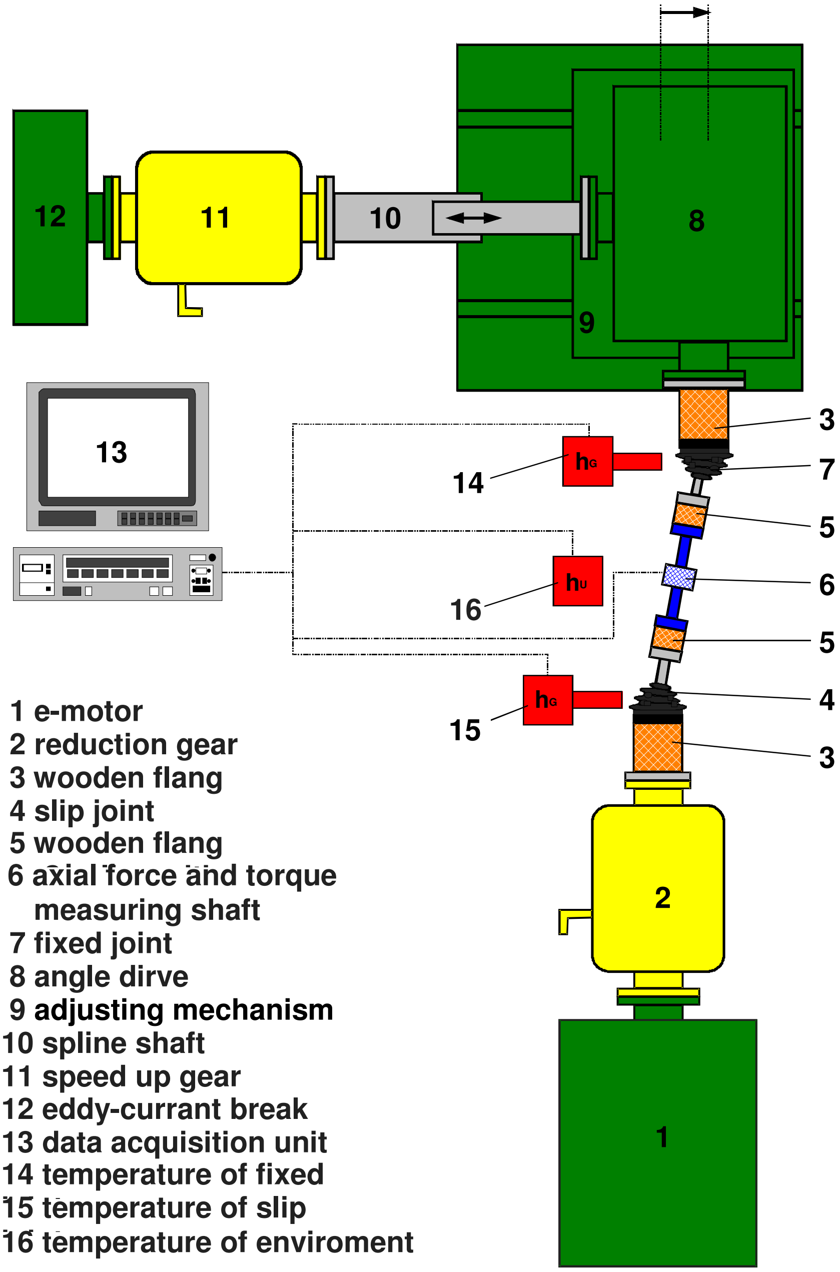

Fig. 4-1: CV-joint test bench

The shaft of the original drive shaft is substituted by the ika / fka measuring shaft. For this purpose both joints are applied with adaptation flanges on both sides (shaft side and test bench side).

The drive train of the test bench is powered by an e-motor (1). The shaft speed and torque range can be adjusted by a reduction gear (2). The thermal insulation of the joints to the measuring shaft and the test bench is realized by wooden flanges (3, 5). In order to ensure the length adjustment (when changing the bending angle), it is necessary to carry out the test routine with one fixed – and one slip joint (4, 7). The operating parameters speed and torque are measured by the measuring shaft (6) and are transferred by a telemetry system to the data acquisition unit (13). The angle gear (8) deviates the power flow at 90°, thus a bending angle adjustment with a short test bench length is possible. The adaptation of the output shaft length is realized by a spline shaft (10). The eddy-current brake needs a higher speed level, which is set by the speed up gear (12). The CV-joint temperature is captured by two pyrometers (14, 15) and the environment temperature by a standard thermometer (16). An illustration of the test bench is shown in Fig. 4-2.

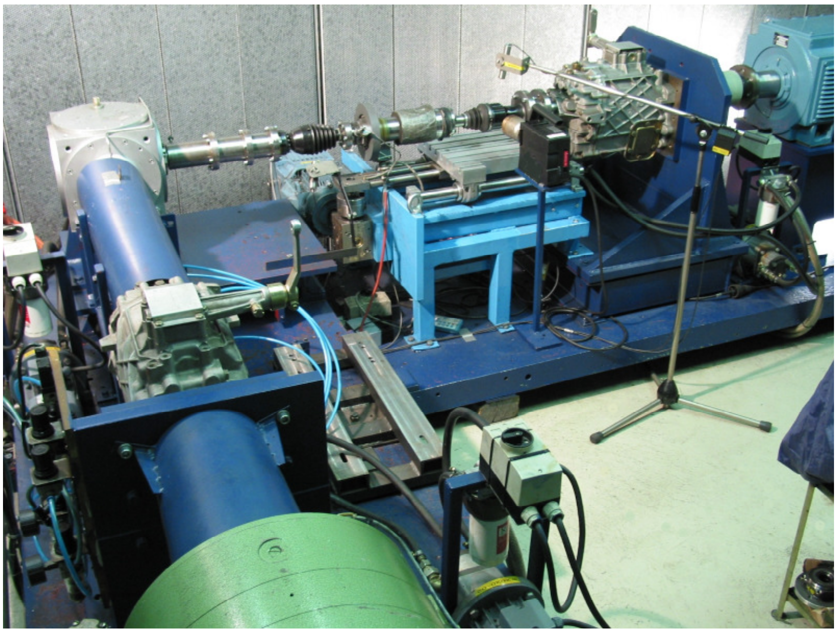

Fig. 4-2: ika / fka CV-joint test bench

The operating parameters bending angle, torque and speed, which have effects on the forces and losses of the CV-joints, can be varied in wide ranges (speed: up to 1000 rpm, torque: up to 1000 Nm, bending angle: up to 18°).

5 Efficiency measurements and results

The test bench with both mounted test joints – the Thomson coupling and the slip ball joint – is shown in Fig. 5-1 on the left side. This is the setup for the running-in procedure. The setup for the efficiency measurement with the wooden insulation flanges is illustrated on the right picture, exemplary shown for the Thomson coupling.

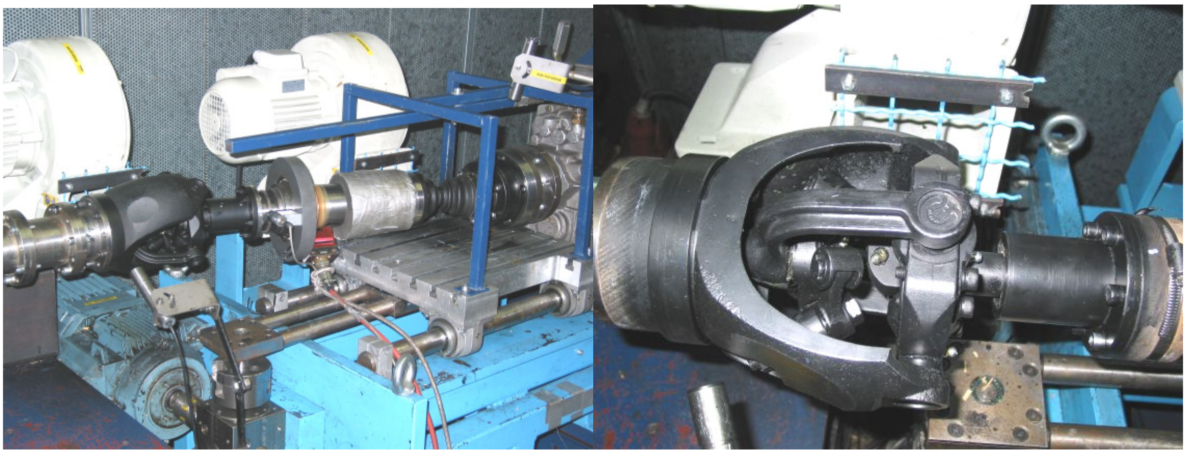

Fig. 5-1: Test bench with fitted test joints

The efficiency measurement of both joints simultaneously necessitates the separated thermal insulation of both joints. This results in a very high length of the shaft with a higher unbalance, thus the required speed of 1000 rpm can not be run with this set up. The efficiency measurements of the joints will be carried out sequentially for this reason.

In order to acquire the specific data values torque, speed and bending angle, the following operating points are set for the testing:

- constant speed (500 rpm) and constant bending angle (5°) with torque levels of 100 Nm, 250 Nm, 300 Nm, 400 Nm and 500 Nm
- constant torque (200 Nm) and constant bending angle (5°) with speed levels of 500 rpm, 750 rpm and 1000 rpm
- constant speed (500) and constant torque (200 Nm) with bending angle levels of 3°, 5°, 10° and 15°

Measurements with high values for torque, speed and bending angle are not possible. The reason is, that the measurement method itself disallows an air cooling of the joints during testing.

In the first step the reference slip ball joint is tested. It reaches efficiency values between 99.22 % and 99.86% (Fig. 5-2 to Fig. 5-5) at all operating points. The variation of torque has only minor influences on the joint efficiency (max. 0.18%). The bandwidth of these values is within the range of the method error. Regarding the influence of speed the joint efficiency decreases from 99.7% (500 rpm) to 99.52% (1000 rpm). The variation of the bending angle results in higher changes of the joint efficiencies. At a low bending angle of 5° a value of 99.86% is determined, continuously decreasing with higher bending angles (max. 15°) to values of 99.22 %.

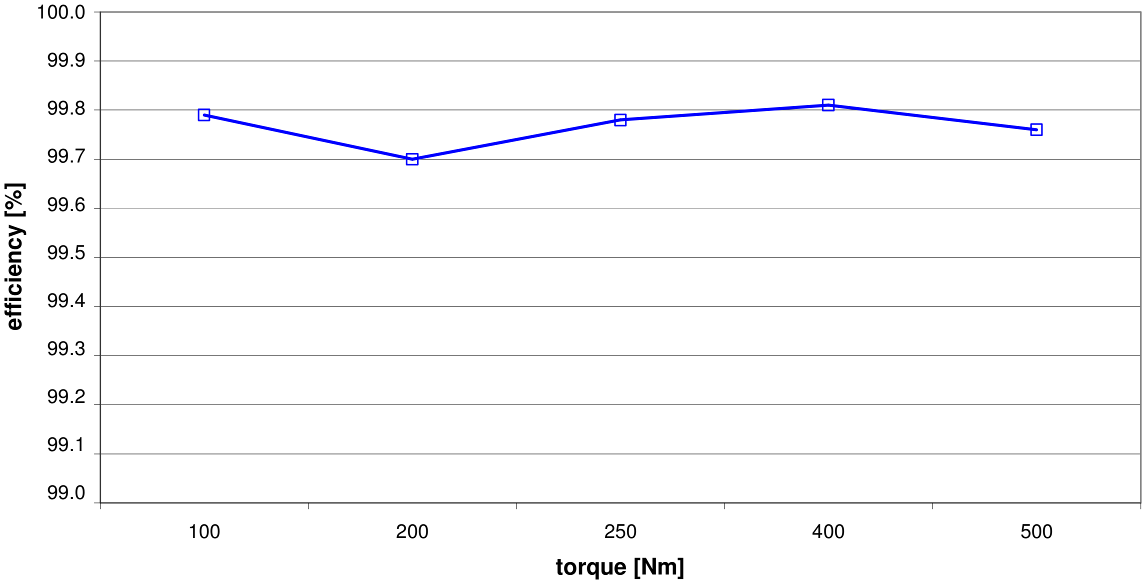

Fig. 5-2: Efficiency of the slip ball joint at 500 rpm speed and 5° bending angle

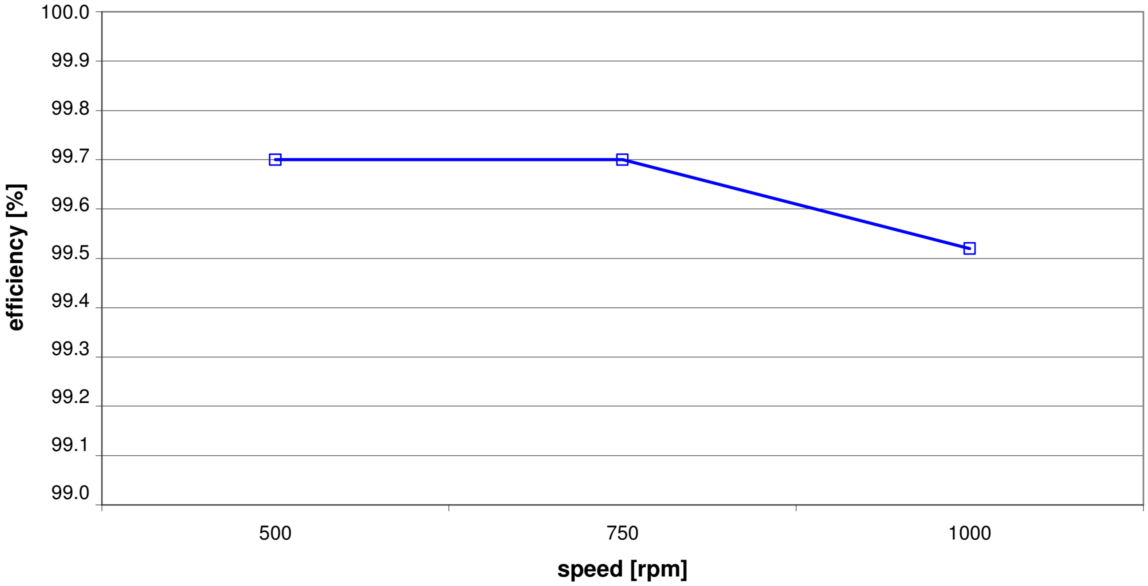

Fig. 5-3: Efficiency of the slip ball joint at 200 Nm torque and 5° bending angle

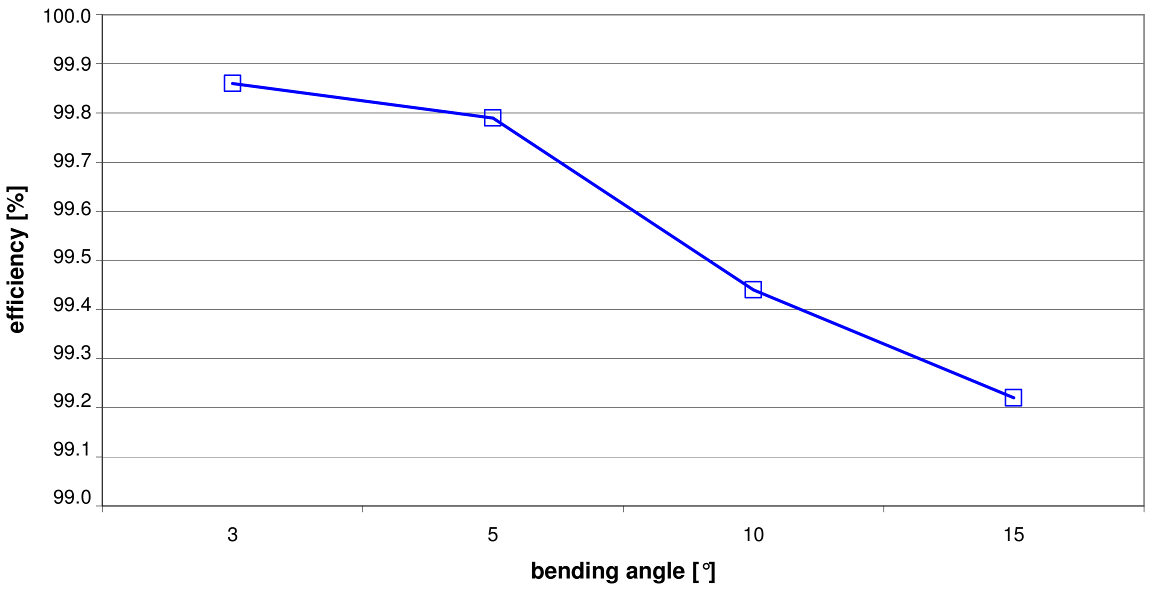

Fig. 5-4: Efficiency of the slip ball joint at 500 rpm speed and 200 Nm torque

torque constant	**200 Nm**
bending angle constant	**5 °**
shaft speed [rpm]	**efficiency [%]**
500	99,70
750	99,70
1000	99,52
speed constant	**500 rpm**
bending angle constant	**5 °**
torque [Nm]	**efficiency [%]**
100	99,79
200	99,70
250	99,78
400	99,81
500	99,76
speed constant	**500 rpm**
torque constant	**100 Nm**
bending angle [°]	**efficiency [%]**
3	99,86
5	99,79
10	99,44
15	99,22

Fig. 5-5: Efficiency values of the slip ball joint

Contrary to standard ball and tripod CV-joints the Thomson coupling reveals a total different behaviour in heating-up and cooling-down temperatures during the efficiency measurements. Standard joints have a heating-up and cooling-down curve as shown in Fig. 3-2 and Fig. 3-4. The gradients of the heating-up and cooling-down temperatures of the Thomson coupling only have small differences, compared to the gradient of the environment temperature, especially for operating points with low bending angle and speed. The ika / fka method is based on the analyses of the specific temperature curves. Therefore the limitations of the method are reached and no efficiency results are available for some operating points. Only measurements with operating points as shown in Fig. 5-6 have analyzable temperature curves. This results in overall joint efficiencies higher than 99,94%. Regarding the maximum possible error of the measuring method, the Thomson coupling has efficiency values better than 99.89% for all measured operating points.

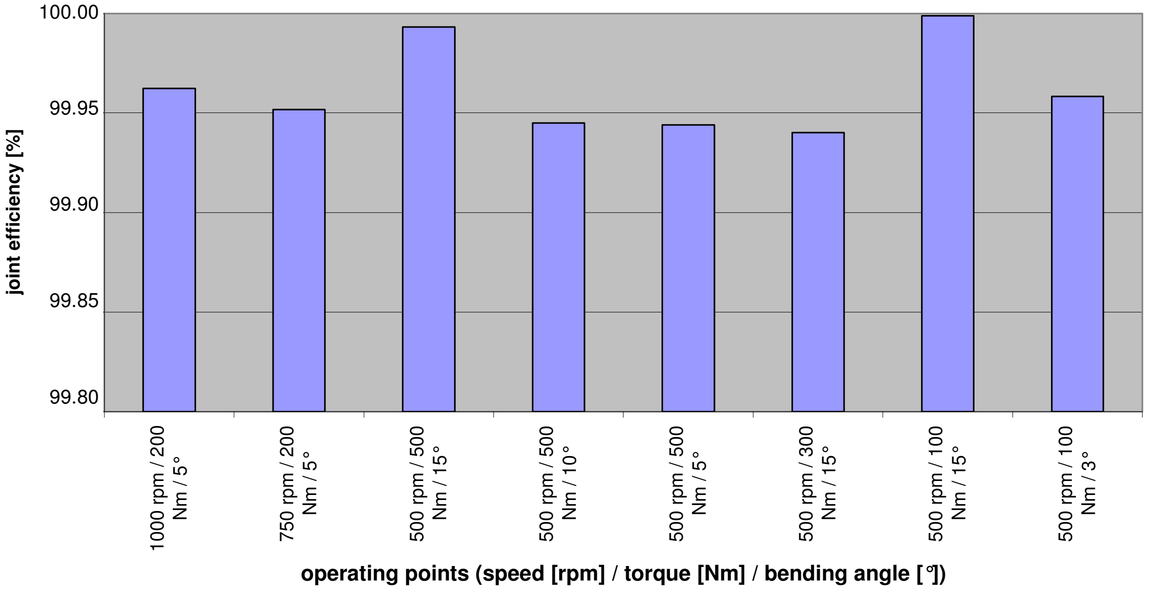

Fig. 5-6: Efficiency of the Thomson coupling

Generally speaking the efficiency of the Thomson coupling is approximately independent from torque, speed and bending angle, unlike standard ball or tripod joints. Hence the Thomson coupling has significant potential to increase the efficiency of drive line systems, for example in automotive applications. Nevertheless higher mass and space requirements of the joint, in comparison to standard fixed ball joints, pose a new challenge in automotive applications.

6 Summary

In most vehicles of the passenger car segment the whole propulsion power is transferred via CV-joints. Therefore even a small improvement of the efficiency of the CV-joints have a positive influence on fuel consumption. Subject of this project was the efficiency measurement of one standard slip ball CV-joint and of one Thomson coupling at several operating points up to 1000 rpm speed, up to 500 Nm torque and up to 15° bending angle.

The measurements were carried out at the ika / fka CV-joint test bench, which is specialized for the measurement of NVH effects and the efficiency analyses of CV-joints. The efficiency measurements are based on the patented high accuracy ika / fka measuring method. The joint efficiencies are calculated by the determination of input or output power and the thermal power loss, which is calculated by the temperature values of the joints and referring to the environment.

The measurement of the standard slip ball joint resulted in efficiency values between 99.22 % and 99.81 %. Changing the torque approximately had minor influence on the joint efficiency (between 99.70 % and 99.81 %). Regarding the joint efficiency, the parameters speed and bending angle have a high influence. The joint efficiency tended to lower values with increasing speed (500 rpm / 99.70 %; 1000 rpm / 99.52 %) and bending angle (5° / 99.86 %, 15° / 99.22%).

The Thomson coupling had efficiency values higher than 99.89% for all regarded operating points. A differentiation of the efficiency between these operating points was not possible, caused by the maximum error tolerance of the measuring method and the analyse method of the thermal power loss, which is based on the analyses of the joint and environment temperature.

In comparison to the standard ball joint the efficiency of the Thomson coupling was approximately independent from torque, speed and bending angle and reached much higher values. Hence the Thomson coupling has the potential to increase the efficiency of drive lines, for example in automotive applications. Nevertheless the higher mass and space requirements of the joint, in comparison to standard fixed ball joints, pose a new challenge in automotive applications.

The positive influence of the good efficiencies of the Thomson coupling on the fuel consumption of a vehicle has to be established by simulations or by automotive measurements, base on different standardized driving cycles. Both can be carried out at ika / fka.