NASA TECHNICAL TRANSLATION TM-75215

HYBRID DRIVE FOR MOTOR VEHICLES WITH A PREPONDERANTLY INTERMITTENT METHOD OF OPERATION

H. Schreck

(NASA-TM-75215) HYBRID DRIVE FOR MOTOR VEHICLES WITH A PREPONDERANTLY INTERMITTENT METHOD OF OPERATION (National Aeronautics and Space Administration) 22 p HC A02/MF A01 CSCL 13I G3/37

N78-12418

Unclas 53588

Translation of "Hybridantrieb für Kraftfahrzeuge mit vorwiegend instationärer Betriebsweise," Institute for Motor Vehicles, Technische Hochschule Aachen, West Germany, Report presented to the 3rd Status Seminar on "Motor Vehicle and Traffic Engineering" November 25-26, 1975 in Cologne-Poll, 17 pages.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 DECEMBER 1977

STANDARD TITLE PAGE

1. Report No. TM-75215

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle HYBRID DRIVE FOR MOTOR VEHICLES WITH A PREPONDERANTLY INTERMITTENT METHOD OF OPERATION

5. Report Date December 1977

6. Performing Organization Code

7. Author(s)
Schreck, H.
Institute for Automotive Technology
Technische Hochschule, Aachen

8. Performing Organization Report No.

10. Work Unit No.

11. Contract or Grant No. NASw-2790

9. Performing Organization Name and Address
Leo Kanner Associates
Redwood City, California 94036

13. Type of Report and Period Covered
Translation

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration, Washington, D.C. 20546

14. Sponsoring Agency Code

15. Supplementary Notes
Translation of "Hybridantrieb für Kraftfahrzeuge mit vorwiegend instationärer Betriebsweise," Institute for Motor Vehicles, Technische Hochschule Aachen, West Germany, Report presented to the 3rd Status Seminar on "Motor Vehicle and Traffic Engineering" November 25-26, 1975 in Cologne-Poll, 17 pages.

16. Abstract

The focal point of this study is the comparison of a flywheel hybrid propulsion system with a conventional propulsion system in a test vehicle under intermittent operation. An energy balance is presented for the conventional propulsion system. This determination has not yet been completed for the hybrid propulsion system. Results so far indicate especially high energy conversion of the gyro component under dynamic operation along with favorable internal combustion engine conditions.

17. Key Words (Selected by Author(s))

18. Distribution Statement
Unclassified-Unlimited

19. Security Classif. (of this report) Unclassified

20. Security Classif. (of this page) Unclassified

21. No. of Pages 20

22. Price

Table of Contents

HYBRID DRIVE FOR MOTOR VEHICLES WITH A PREPONDERANTLY INTERMITTENT METHOD OF OPERATION

H. Schreck
Institute for Automotive Technology
Technische Hochschule, Aachen

1. Purpose for Developing the Hybrid Propulsion System /2

The use of the hybrid propulsion system with gyro is oriented towards cyclic operation. The characterization of such operating conditions is possible by means of representative cycles. General energy information can also be supplied by average velocity and cycle dynamics. The spreads for the mean velocity v_m and the dynamic factor f_D are described by three European cycles:

	$Vm/\frac{m}{s}$	f_D
Europe cycle	5.18	0.015
Aachen cycle	5.62	0.024
Fakra cycle	5.33	0.024

For such cycles the recoverable braking energy of different vehicles can be determined [1].

Fig. 1 shows this energy with respect to the total energy necessary to overcome resistance to rolling, air resistance and resistance to acceleration (W mec. conv.) for the range of above mentioned cycle dynamics. The calculation is based on average vehicle data.

A standard passenger bus which moves primarily in the upper cycle dynamic range uses about 60% of its total converted energy for acceleration.

The range of small trucks and passenger cars is somewhat

---

* Numbers in the margin indicate pagination in the foreign text.

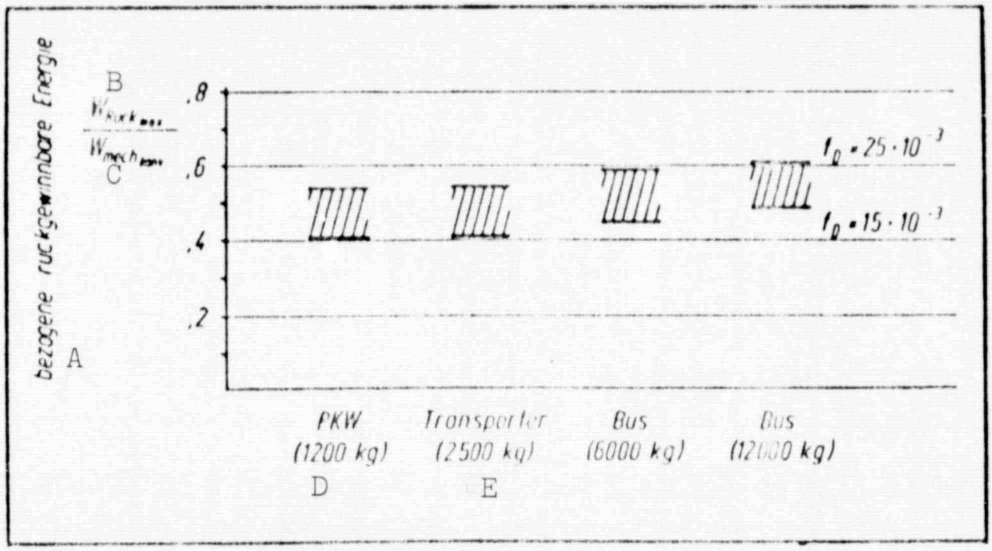

Fig. 1. Relative recoverable energy values for vehicles under cyclic operation.

Key: A) Relative recoverable energy
B) $W_{rec.\ max.}$
C) $W_{mec.\ conv.}$
D) Passenger car
E) Truck

lower than this, being 41-54%. Thus the place value of regenerative braking is considerable, in particular with vehicles of large mass and cycle dynamics. For this reason particular emphasis was placed on developing a more efficient braking energy storage system. This was one objective in developing the hybrid drive system with gyro. /3

The second objective was to improve the operating conditions of the internal combustion engine by uncoupling the sharply fluctuating propulsive power applied to the drive gears and thus make possible slower regulation at smaller dimensions.

This drive system was designed for a small truck. Its structure, function and operation have already been described in [2,3,4].

ORIGINAL PAGE IS
OF POOR QUALITY

Fig. 2 shows a picture of the drive system.

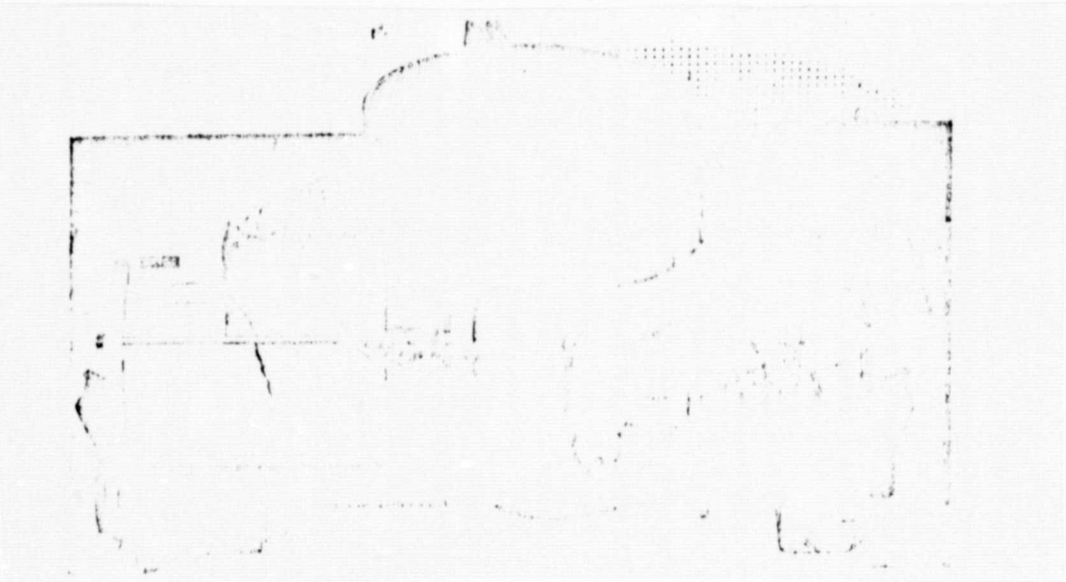

Fig. 2. Hybrid drive system with flywheel as experimental drive system.

2. Developmental Work on the Drive System

In the first developmental stage the drive system was put into operation after a short construction period. Both the test stand experiments and the driving experiments proved to be operational. During operation there were a few detail problems which for the most part it was possible to eliminate in the course of further development and improvement.

2.1 Mechanical Components

The wankel engine which was installed exhibits very adverse rotary oscillation behavior, especially in the low rpm range. This presented problems in hooking up to the flywheel. With transmission parts it was indeed possible to mitigate this effect, however a complete remedy could not be immediately achieved. Moreover, since the engine showed an unfavorable performance graph which could not be reproduced with certainty, it is intended /4 to eliminate these difficulties by replacing the engine with a lifting cylinder engine. In dynamic operation it turns out that the gyro was discharged somewhat more strongly than expected. This forces the internal combustion engine into the lower, critical rpm range. For this reason an altered drive system was constructed with somewhat greater gyro energy. Because of unavoidable long delivery times for gear parts it has not yet been possible to collect any practical data with this drive system. In the meantime it has been installed and is currently being subjected to operational tests [5].

Safety aspects in the design of the new gyro have also been taken into account here by observing lower material load values. In operating conditions these lie in the range of about 140 N/mm^2 (Fig. 3).

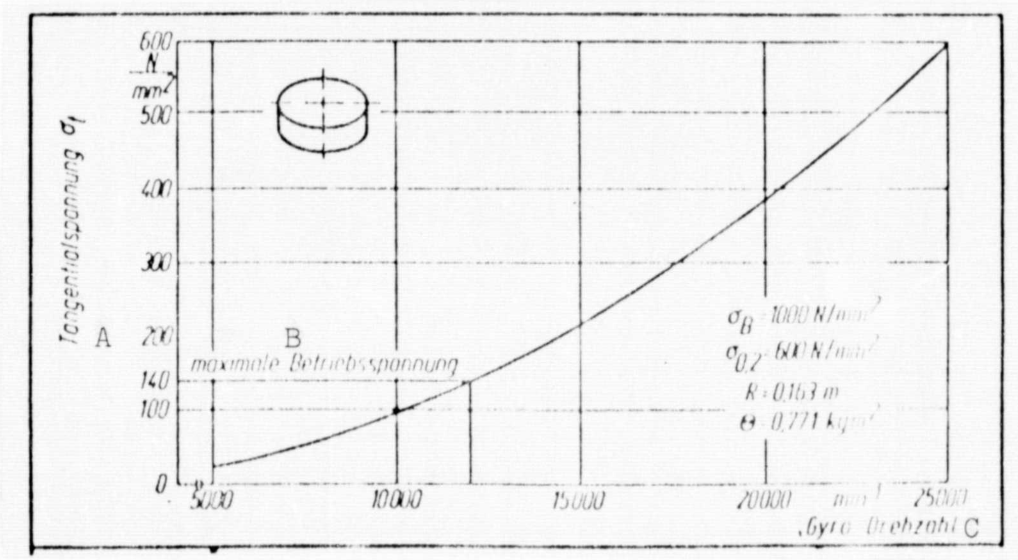

Fig. 3. RPM and tangential stresses of a steel flywheel for the hybrid drive system.

Key: A) Tangential stress
B) Maximum operational stress
C) Gyro rpm

Passive safety problems were tackled by constructing a special test stand for testing flywheel casings [6].

Even after a rather long period of operation the inherent production of the planet gear together with gyro and storage prove to be functionally efficient and not susceptible to breakdown. Empirical data and computations show that when using a relatively small gyro centrifugal forces do not cause any problems even when the vehicle is moving at high speeds.

2.2 Electrical Components /5

When the vehicle is accelerating and decelerating the electric motor must run for a short time in the overload range. This caused damage to the electric motor. After measures taken to improve cooling proved unsatisfactory the load on the motor had to be reduced by decreasing the maximum current. This had a direct effect on the driving performance and the gyro load. However, it was possible to prevent further damages by this measure.

To keep the battery in an average charge state the i.c. engine and electric motor have to be adjusted with appropriate timing constants. A suitable control quantity for this is the no-load voltage of the battery dependent on the state of charge. A field plate sensor developed for this purpose determines free of potential the average no-load voltage which [is] fed to a regulating electronic device and, depending on the state of charge of the battery, activates the throttle valve control or the charging current control. This control system is still in the developmental stage so that for the time being only the no-load voltage can be controlled.

With the inherent development of the control electronics to expand the drive range of the electric motor to 4-quadrant operation and 2-pedal control no problems have developed so far. The control and regulation characteristics have been further improved.

3. Test Preparations

3.1 Experimental Setup and Measurement Method

Exact evaluation of the operational system is only possible when a sufficient number of measurements can be made simultaneously. Since a suitable tape storage device was not yet available, driving tests could be carried out only on the Institute's own rolling test stand. With this, however, it is possible to change the simulated weight (1250 or 2060 kg) by connecting or disconnecting the electric motor of the test stand. With the characteristic loss curve of the test stand, which is dependent on velocity, it was possible after a few adjustment problems to achieve a good approximation of real road resistances for the simulated weight. With rolling experiments equivalent test stand conditions were guaranteed.

Determination of the power and energy efficiency requires continuous measurement of the fuel flow rate and fule consumption for a driving cycle. /6

A suitable commercial measuring device had to be adapted with a homemade accomodating connection to the signal level of the analog computer used for the evaluation. It was necessary to make rpm measurements at several points of the drive system. They were made with tacho-generators. Occasionally a more accurate method is required for determining the gyro rpm. It was possible to meet these requirements by using a homemade tachometer with differential field plate indicators. The torque transmitted from the drive shaft of the vehicle was measured with a non-contact torque measuring device. The considerable interference effects stemming from the impulse control of the drive system particularly reduced the accuracy of the measurements

Since the elimination of these problems required spending a rather large amount of time, the starting torque was determined artificially from the travelling velocity and continuously checked and if necessary corrected with rolling experiments. On another vehicle, the comparison of measured and artificially determined torques gave very good agreement.

It was not possible to measure the energy conversion of the electric components with the means available. Since this especially applies to the battery, it was attempted at least to measure the terminal output of the battery in driving operation. Because of the occurrence of very steep inpulse peaks the relevant signals cannot be measured with simple means. An instrument developed for this purpose is currently being tested.

For the time being, in order to make it possible to evaluate the electric components at least by computation these were studied under stationary conditions. This study was kindly taken over by Prof. Skudelny of the Institute for Converter Technology, Aachen Technical Hochschule. The results, especially in the armature position region of $\eta_{max} \approx 0{,}6 / 0{,}45$ for motor and generator operation respectively, were not very favorable. In the field position region the values measured were 0.8 and 0.65 respectively.

3.2 Evaluation Technique

The large number of measurements occurring during the course of the test can best be processed by an analog computer. With a computer program designed for this purpose it was possible, for /7
example during a cycle trip, both to monitor the progress of the experiment and directly register the computed test results. Fig. 4 illustrates the range of this program.

By means of the individual records the evaluation possibilities may be briefly illustrated as follows:

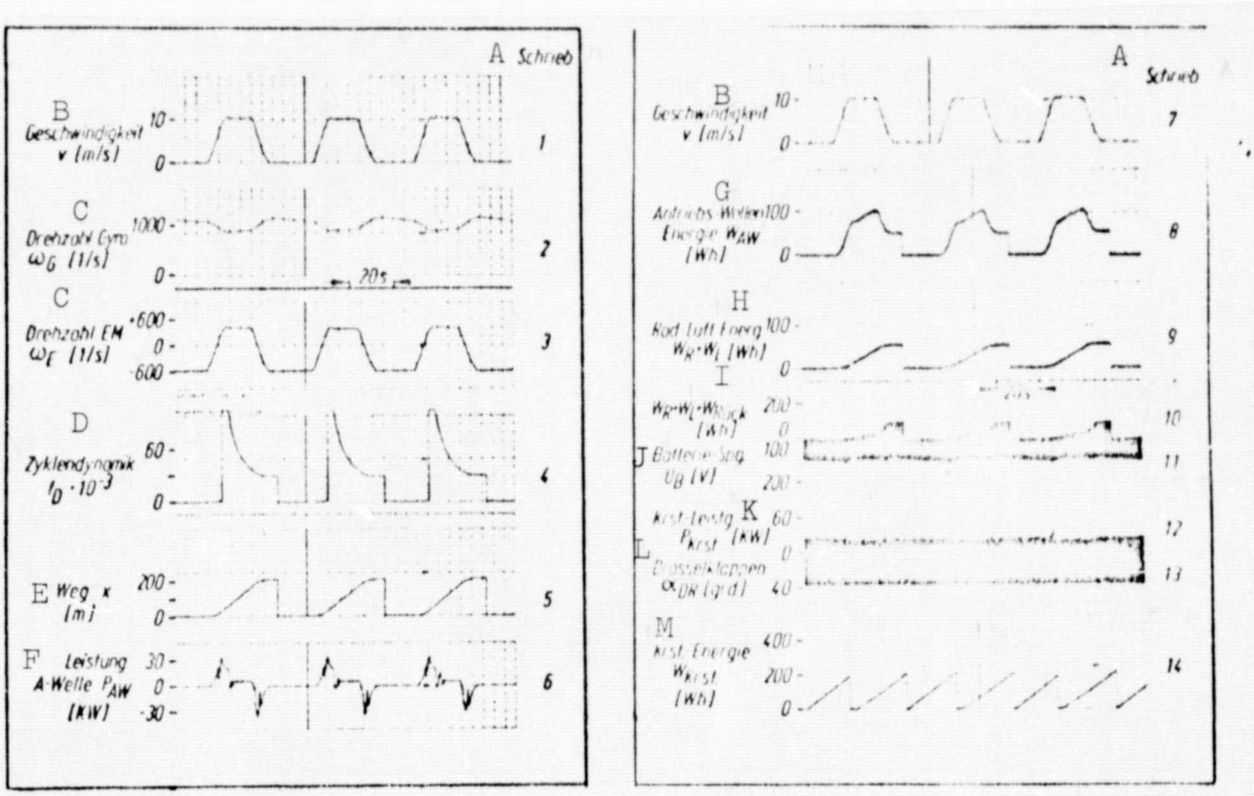

Fig. 4. Measured and computed results with the hybrid drive system during cyclic driving.

Key:
A) Record
B) Velocity
C) rpm
D) Cycle dynamics
E) Distance
F) Output, driveshaft
G) Driveshaft energy
H) Wheel resistance energy, air resistance energy
I) Wheel resistance energy, air resistance energy, recoverable energy
J) Battery voltage
K) Fuel power
L) Throttle valves
M) Fuel energy

<u>Record 1</u> represents the velocity over time of the drive through the cycle. Differences in cycle dynamics and average velocity were obtained by varying the maximum velocity, the constant drive portion and the accelerations of the cycle.

<u>Record 2</u> represents the changes in gyro rpm over time. At first it was intended here to record directly the energy taken

up and given off by the gyro, since this is easy to measure. However, only the gyro prm was recorded.

Record 3 illustrates the drive operation with the electric motor rpm which is negative when the vehicle is at rest and positive here during constant travel.

Record 4 shows the changes in developing cycle dynamics over time during the trip through the cycle. During accelerating travel it reaches high values proportional to the acceleration. Since only positive acceleration components (and no deceleration components) are evaluated, it decreases sharply with increasing distance. The end value reached represents the cycle dynamics for the distance covered.

Record 5 is the graph of the distnace covered per cycle.

Record 6 indicates the propulsive output which is expressed as a control quantity.

Record 7 again here shows the velocity.

Record 8 shows the change in propulsive energy over time. It is determined by integrating the propulsive power, which is easy to check, expressed in record 6. Since integrations are made over positive and negative energies, the energy demand is reduced at the start of braking by an amount equal to the recoverable portion of the kinetic energy. The end value represents the pure loss energy value of the wheel and air resistance. This is plotted again separately in record 9.

Record 10 represents a superimposition of records 7 and 8 in which the wheel resistance energy and air resistance energy and the recoverable energy are added up with opposite signs. By extending the program this makes it possible to directly determine the degree of energy efficiency.

Record 11 shows the intended, determined no-load voltage of the battery for regulating the state of charge.

Records 12 and 13 show measured values for the internal combustion engine. Above is plotted the analog represented fuel power, and below the setting of the throttle valve for 1 cycle operation. /8

Record 14 adds up the digital fuel consumption impulses.

3.3 Experimental Procedure and Results

To ensure constant test conditions the rolling test stand and the vehicle both had to be brought to an operating tempera- /9 ture which precluded a change in operating conditions during the course of the test.

The runs are varied by varying the maximum velocity, travel acceleration and the amount of driving time at a constant speed and stationary time. The measurements were checked by periodically repeating identical cycles. The first operational data using the measurement and evaluation system which could be easily modified for this purpose was obtained by determining the characteristic data for a conventional small bus.

The test results, recorded on measuring tapes, are automatically plotted in a 2-quadrant representation (Fig. 5).

This graph illustrates the energy relationships of a vehicle during cyclic travel. In the first quadrant are plotted relative mechanical energy values for wheel resistance and air resistance $W_R + W_L$. The agreement between measureed values and calculated values is very good in this case. In the second quadrant are

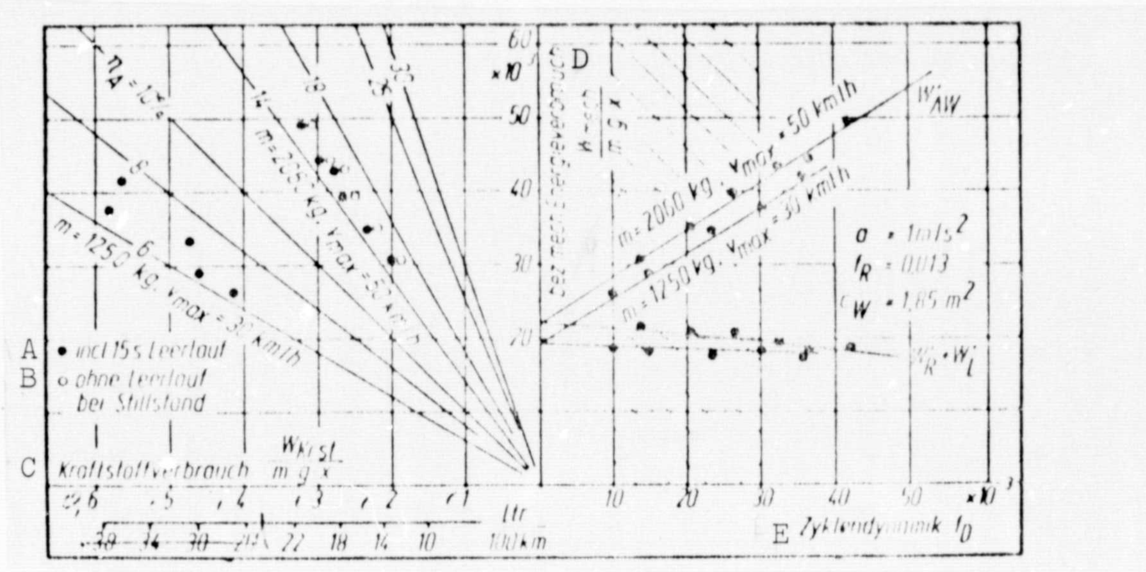

Fig. 5. Diagram for determining the relative energy consumption.

Key: A) Including 15 seconds of idling
B) Without idling while stationary
C) Fuel consumption
D) Relative mechanical energy consumption
E) Cycle dynamics

represented the accompanying degrees of propulsive efficiency calculated from driveshaft energy and fuel energy for individual cycle dynamic values.

With a higher vehicle weight and a maximum velocity of 15 km per hour the efficiencies prove to be relatively independent of the cycle dynamics. At a smaller velocity (30 km per hour) and with a lighter vehicle (m 1250 kg) they all decrease sharply. The influence of consumption during idling (about 0.8 liters per hour) when the vehicle was standing still (15 seconds) proved to be small.

Another interesting result is the cycle efficiency η_{cycle}. (Quotient of wheel and air resistance energy over fuel energy.)

In Fig. 7 [sic] this cycle efficiency is plotted as a function of the average travelling velocity for two cycle acceleration values and two vehicle weights. /10

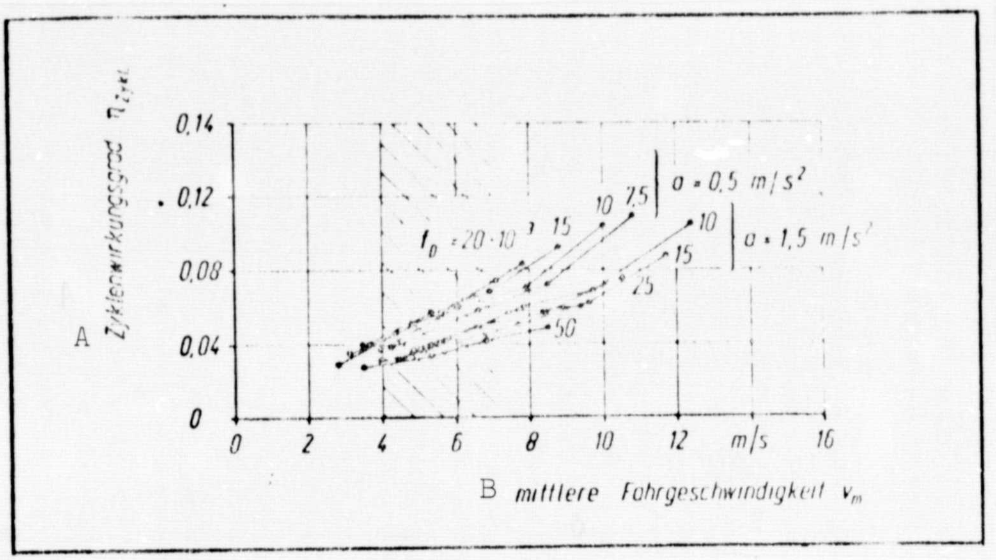

Fig. 6. Cycle efficiency plotted over average travelling velocity for conventional vehicles.

Key: A) Cycle efficiency
B) Average travelling velocity

This information become unreliable as the frequency of shifting increases (dispersion of values at higher velocities). The effect of vehicle acceleration can be clearly distinguished. The efficiency values drop with higher acceleration values independently of the weight of the vehicle at the same average velocity. Thus only 3-8% of the fuel energy is used in the predominantly occuring velocity range of V_m = 4-7 m/s to overcome wheel resistance and air resistance.

The series of test were carried out for a rather large range of operation so that a good overview of the behavior of the vehicle during cyclic travel could be obtained. At the same time this can be used as a basis for comparison with the hybrid vehicle. Up to now it has not been possible to draw up an overall balance for the hybrid vehicle, since it was not possible to determine the energy conversion of the battery. However, test stand experiments with partial results have been performed.

The driving performance of the vehicle is sufficient to drive even demanding cycles. The average acceleration for 0-50 km per hour is around 1.2 m/s^2.

The exchange of energy between vehicle and gyro represents an important characteristic of the drive system. The relationship shown in Fig. 7 was determined from a series of tests.

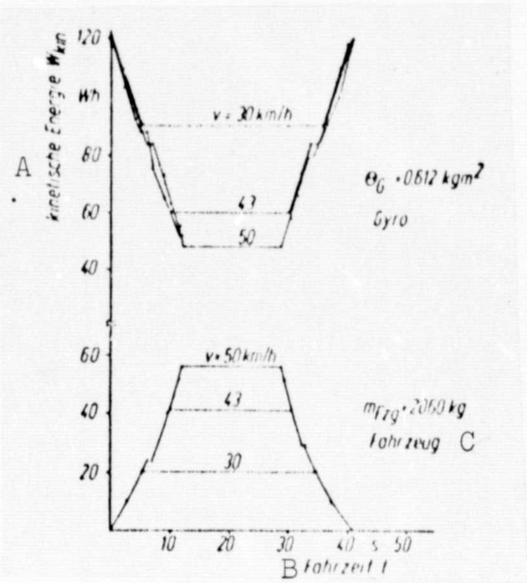

Fig. 7. Energy conversion of gyro and vehicle at optimum power output of the internal combustion engine.
Key: A) Kinetic energy
B) Driving time
C) Vehicle

By suitable desing it was possible to make it so that the energy given off by or taken up again by the gyro is on the order of magnitude of the kinetic energy of the vehicle. The discharge rates are largely dependent on the velocity. This confirms an important point of the drive system concept, that of short-term energy storage by means of a flywheel. /11

In the absence of direct battery measurements another important result, namely the operational range of the internal combustion engine components, could only be acquired by long-tests. It was plotted in the performance graph (Fig. 8) for cycle dynamic values up to 0.04 and maximum velocities up to 50 km/h. The throttle valve angles roughly corresponded to the maximum velocities of 20, 30, 40 and 50 km/h during cycle travel. The higher values terminate in the limiting characteristic curve of the engine and thus indicate a somewhat small-sized engine for the simulated vehicle weight. All together, however, the realization of the narrow operational range of the internal combustion engine with the requirement for dynamic performance of the drive system can be demonstarted.

/12

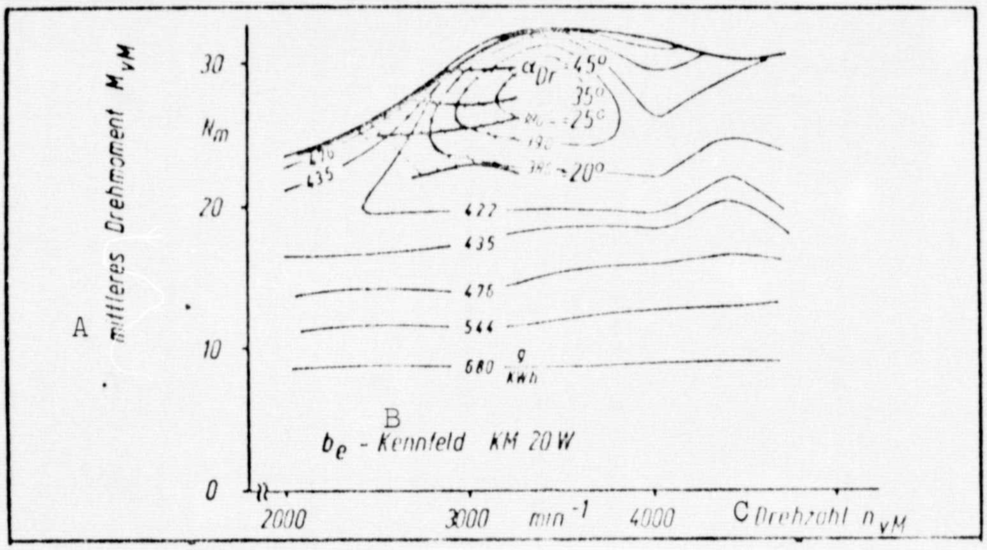

Fig. 8. Performance graph and operational range of the hybrid drive internal combustion engine.

Key: A) Average torque
B) Performance graph
C) rpm

4. Computer Results

In parallel with the experimental testing of the drive system a digital computer model for the hybrid vehicle was further developed. It was used to study design problems of the drive system. The problem of the gyro in this connection is particularly interesting.

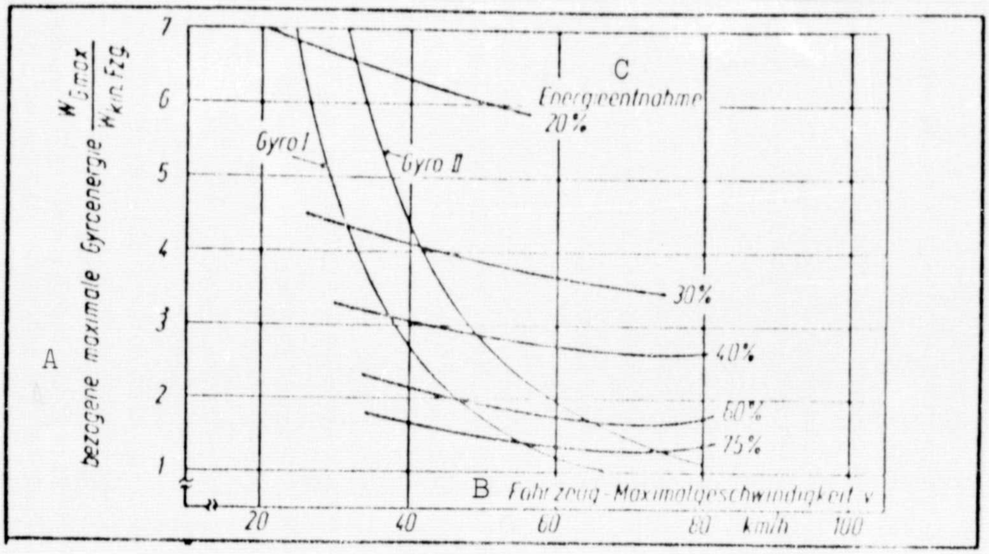

Fig. 9. Diagram for designing a gyro for hybrid propulsion.

Key: A) Relative maximum gyro energy
B) Vehicle maximum velocity
C) Energy removal

With Fig. 9 the gyro can be designed as a function of the maximum travelling velocity to be achieved and as a function of its discharge. The quotient of the maximum energy stored in the flywheel (WG_{max}) and the kinetic energy of the vehicle at maximum velocity (W_{kin}) is here independent of the weight of the vehicle for a given discharge and largely proportional to the travelling velocity called for in the design. The graph also shows the lines for 2 completed gyros for the hybrid drive system.

The results obtained are in good agreement with the experimental data.

With optimum transmission stages of the summing gear the mechanical energy conversion was calculated for the acceleration of a vehicle weighing 16 tons, since the energy share of the electric components is particularly interesting here. The graph produced by the computer is shown in Fig. 10.

ORIGINAL PAGE IS
OF POOR QUALITY

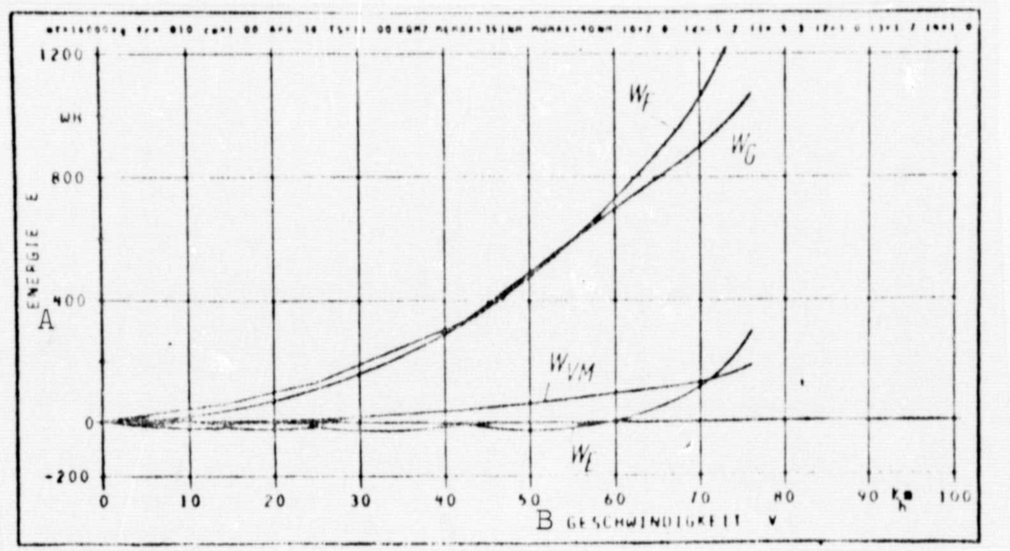

Fig. 10. Mechanical energy of hybrid propulsion system components during intermittent travel for a test vehicle.

Key: A) Energy
B) Velocity

The curves show the high proportion of energy of the flywheel W_G out of the total energy W_F for the vehicle to be used for dynamic operation.

The mechanical energy conversion of the electric motor W_E is on the whole relative small, likewise that of the internal combustion engine W_{VM} which is set for 50 km/h cycle travel. Occasionally in the case of constant (i.e. non-intermittent) operation not shown here the energy component of the electric motor can increase, corresponding to about 1/3 of the energy converted by the internal combustion engine. After the electric components proved to be not very efficient in operation developmental emphasis was placed on reducing the proportionate energy conversion of these components. Changes were made in the regulation of the drive system in order to alter the operating behavior of the electric motor and by modifying the design of the drive system the distribution of power between the components was suitably modified.

5. Prospects

/14

During intermittent operation (ordinary cycles with a dynamic factor of 0.01-0.03) trucks with conventional internal combustion engines in the loaded state convert a maximum of 15-16% of the fuel energy into mechanical propulsive energy at the wheels. In the unloaded state they convert only 6-10% of the energy (propulsive efficiency). Of this mechanical propulsive energy a fraction of about 41-54% is used for acceleration and is not recovered. The resulting cycle efficiency (ratio of wheel resistance and air resistance energy to fuel energy) is 3-7%.

The aim of the hybrid drive system with gyro component studied here is, on the one hand, to improve the propulsive efficiency in such a way that the power for acceleration is essentially supplied by the gyro, i.e. the internal combustion engine designed smaller (to avoid adverse partial load ranges) and, on the other hand, to recover a larger portion of the acceleration energy during braking with the gyro.

Both operations are fulfilled by the drive system, i.e. in particular by the flywheel. With a nearly constant output of the internal combustion engine of about 5-10 kW (range 0-40 kW) usual dynamic driving performance is realized by means of the flywheel. During acceleration and braking the kinetic energy of the vehicle is essentially supplied and stored up again respectively by the flywheel.

A complete energy balance for the hybrid vehicle is not yet presented here quantitatively because it has not yet been possible to precisely determine the energy balance of the battery. Since for the time being this cannot be accomplished in the time available, the possible error is reduced by means of long-term experiments in such a way that sufficiently precise information is possible. The results obtained from the first experimental drive system suggest that the drive concept is promising, in particular for heavy vehicles with strongly intermittent operation. Here it should also be mentioned that there are also advantages for the use of unconventional internal combustion engines which, when they are the only source of power, can meet only with difficulty the strict dynamic performance requirements of cyclic travel. The next intended area of application under consideration is the passenger bus.

REFERENCES

1. Institute for Automotive Technology, Aachen Technische Hochschule,: Internal Report No. Di 378.

2. Helling, J., B. Giera and H. Schreck, "A hybrid drive system with gyro component for economic and dynamic operation," ETZ-A 94/11 (1973)

3. Helling, J. and H. Schreck, "Efficiency of a hybrid drive system with a kinetic storage unit, used in intermittent operation," 15th FISITA Congress, Paris, May 13-17, 1975, Report B-2-8, pp. 317.

4. Schreck, H. and F. Torres, "Hybrid drive system with kinetic energy storage unit as a vehicle drive system," 2nd Symposium on Low Pollution Power Systems Development and 2nd Status Seminar on Vehicles and Traffic Technology Nov. 4-8, 1974, Düsseldorf.

5. Institute for Automotive Technology, Aachen Technische Hochschule, Internal Report No. Wa 527.

6. Institute for Automotive Technology, Aachen Technische Hochschule, Internal Report No. Wa 538.

7. Runge, W., "Studies on lead storage batteries, dissertation, Reinische-Westfälische Technische Hochschule, Aachen, 1973.

8. Kahlen, H. and W-D. Weigel, "Comparative measurements on different electric motors for experimental passenger vehicles," ETZ-A 94/11 (1973).

9. Institute for Automotive Technology, Aachen Technische Hochschule, Internal Report No. Di 392