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A MODULAR MACHINE MONITORING AND DIAGNOSTIC SYSTEM FOR DIESEL-DRIVEN MINING VEHICLES

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ABSTRACT: Mining vehicles are often driven by a diesel engine and a power transmission with hydrostatic or hydrodynamic subsystems. The development of a machine monitoring system was initiated by several investigations of failure distributions of monorail diesel trolleys, which pointed out that these main components are causing most breakdowns or the major portions of the maintenance costs Furthermore the analysis of maintenance activities in a German hard coal mine uncovered that the annual maintenance costs of a monorail diesel trolley make 43 per cent of the vehicle's new price and for nearly one third of the repairs the failure was not recognised while the vehicle was in the maintenance shop for the first time. Condition monitoring is a suitable method to assist the workshop staff in finding defects and to maintain equipment in a more efficient way. To support condition-based maintenance of dıesel-hydraulıc drives a modular machine monitoring and diagnostic system has been applied to monorail trolleys, mining locomotives and recently shovel loadeis It is generally adaptable to all kinds of diesel-dnven vehicles. The systems architecture will be presented by its first-time application in a German hard coal mine, where it is part of a more complex maintenance planning system The focus will be on the features for engine diagnostics New diagnostic experiences with hirbocharged diesel engines which are common in surface vehicles will help to adapt (be system to surface applications with state of the art supercharged diesel engines

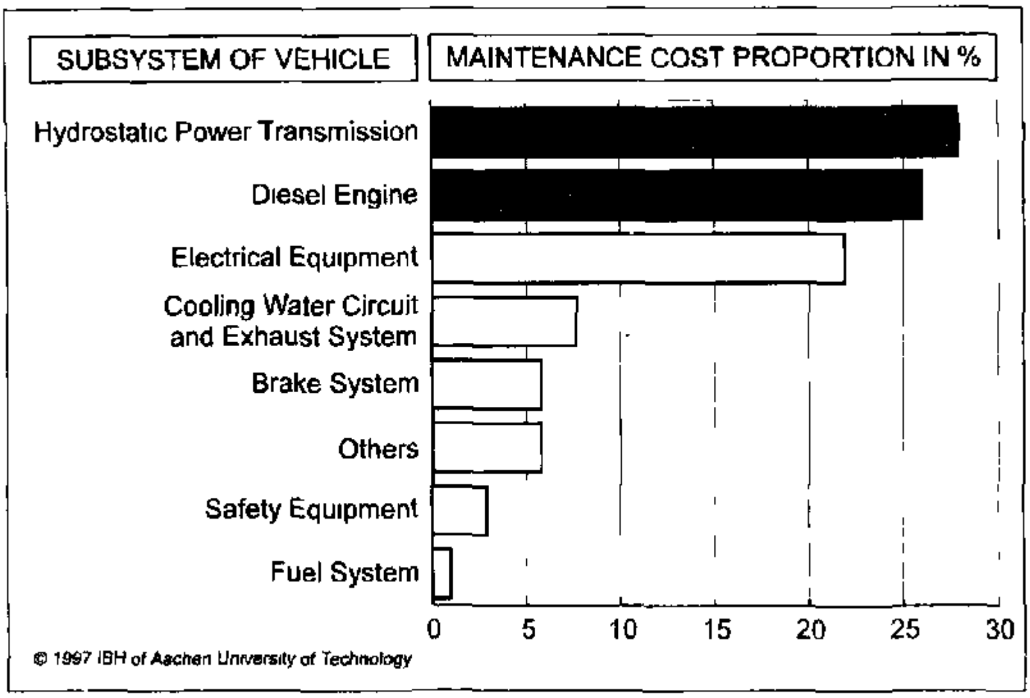
I INTRODUCTION

In the production process and in those fields that help maintain European mining operations, diesel-powered vehicles are often used. Their task is to transport the debris produced, for example coal, ore, salt, as well as to handle the materials needed for production. Particularly in undergtound mining the transport of materials is very important

Investigations of the running expenses of diesel-powered transport vehicles in the German coal mining industry disclosed that the annual costs for maintenance and repair work of a single vehicle can be up to 43 per cent *of* its cost price The study also showed that during the two years of observation il took on average one half *of* a shift to complete the maintenance of a monorail diesel trolley Although up to two oui of three shifts were spent on the maintenance of these vehicles, defects or even breakdowns leoecuired between the ninth and fourteenth shift on duly The; analysis of the maintenance strategy led to the conclusion that due to the fixed maintenance intervals the actual condition of the vehicles was ignored and the repair work was earned out onlv after defects had occuned In summary, the study concluded that in tetms of utilisation the maintenance costs were too high (Linnartz, 1992)

On a more technical level these investigations identified those components which most often are lesponsible for a vehicle bieakdown and dehveied the related distribution of the lotal maintenance costs (wages and costs of replacement parts) of each subsystem (Fig I) The distribution shows that reasonable savings mav he realised by focusing on the subsystems of hydraulic power lıansmıssıon and diesel engine

The need of a high availability and minimal maintenance costs of the mining vehicles studied requires a change of the maintenance strategy lo a condition-based mainienaruc, where the extent and lime of maintenance depend on llie actual Male of the machine To di'teiniinc ihc umdılıon of the vehicle's subsystems and its components a computer-based diagnostic system called RUDI was developed UUDI is an abbreviation fin lechneiuiileistutztes Diagnosesystem fur dieseihydiaulische Antriebe', winch is



I ig I Distribution of total maintenance costs of monorail diesel trolleys with hydrostatiL power transmission

the German translation for 'computer-aided diagnostic system for dtesel-hydraulic drives

2 SURVrYOr FHE VRHJO I MONIfORING AND DIAGNOSTIC SYST EM

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Die *full* version of (he diagnostic system RI/ÎN in dudmg IApul sy.iim and MPCS interlace In. bu n used in a Gaman io.il nunc since Pchiuaiy I'·' H is used thcie loi the diagnosis of IIIOIUHHI' ılı »I tiolk'vs winch iranspoil span.' parts (S<ılı»u ii I 1'J'M)

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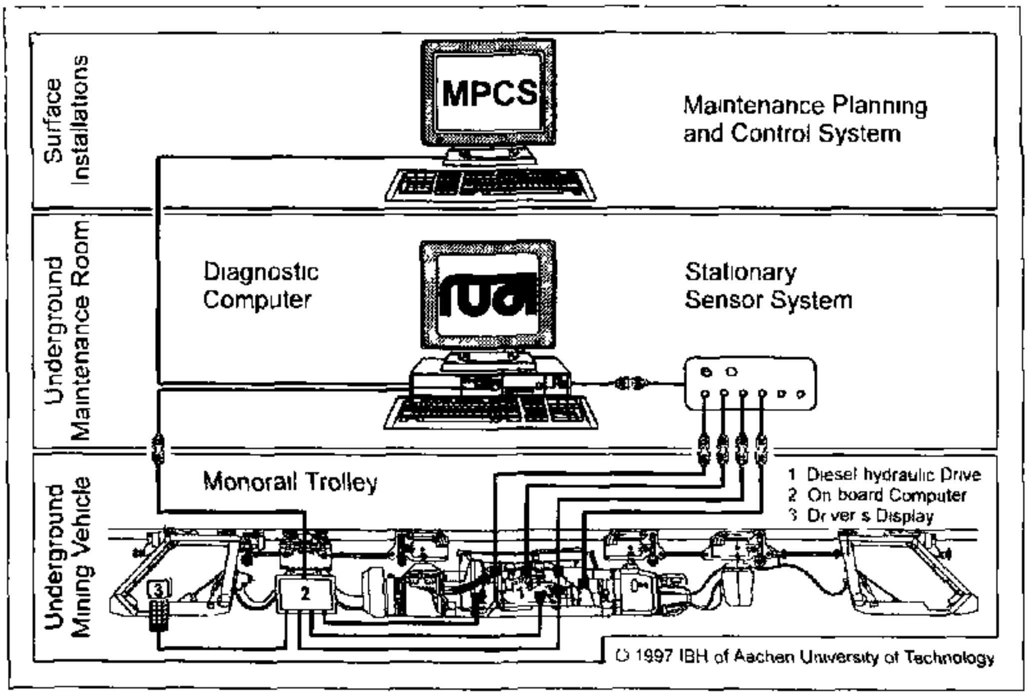

Fig 2 System overview I - diagnostic system as a part ot a maintenance platinini, and control system toi transport vehicles in underground mining

the vehicle's utilisation and to calculate maintenance intervals

The stiess ot the diesel engine is determined and re-corded from the engine torque and the exhaust gas

tempualuie f stımatıon of the enguu s cDıcıcncy is possible it electronically controlled injcetois are available I irst operational expcnuiccs \uıt teamed with lour monoiail diesel trolleys thai hau been equipped with an on board cumpulei ami Id sensin s to monitor the utilisation ol İhı dıcscl uıgiııc and h\ thostalu transmission Un. evaluation ni then load data ri vc lied lhai during the monitored unit intcr\dl flic vtlmlts wölket) tor almost So pu uni ol ıhı Mme with LxiicmeJv low powci

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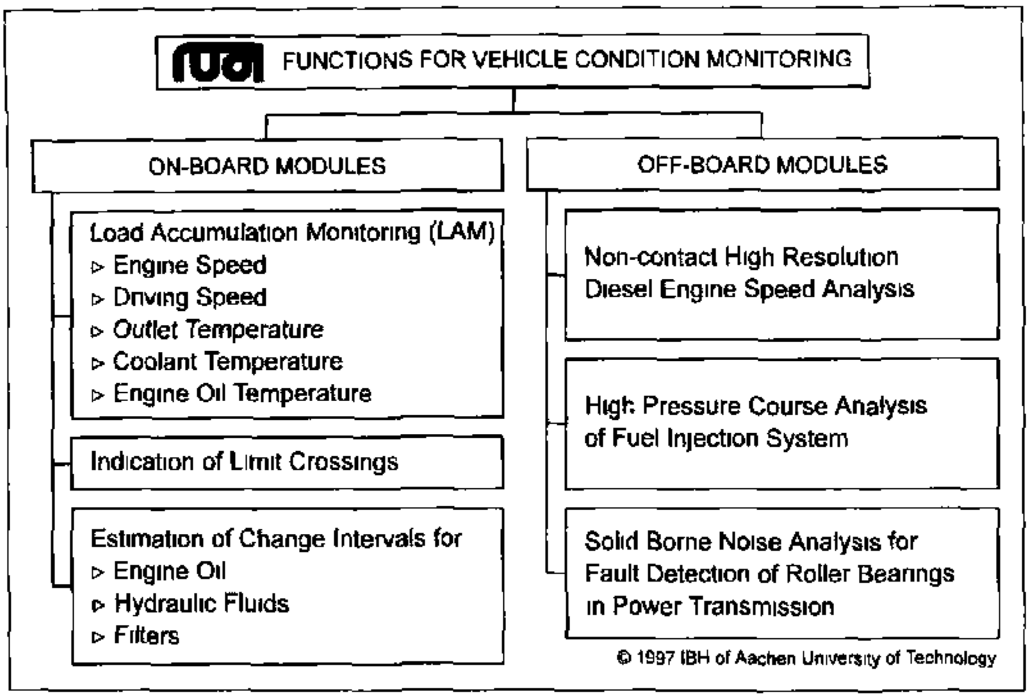

Fig 3 *System* overview *il* - applied monitoring and test functions

condition of the fuel injection system for example faulty settings or wear in the pump and nozzles

A diagnostic module for condition monitoring of a converter's rotating components particularly the damage-endangered roller beanngs and gearwheels is optionally available It is based on the analysis of solid-bome noise signals that are recorded by extremely low-priced and robust acceleration sensors - so called knock sensors - which are used in the automobile industry for detecting malfunctioning combustion

The subsequent signal processing forms a *diagnosis* characteristic by means of an envelope curve analysis This method assisls in diagnosing the bearing damage even in complex systems for example on a diesel rail s converter (Keßler 1994)

2 1 Maintenance support with an expert system

The expert system provides an effective support for the maintenante staff in finding machine faults The implemented knowledge concerning specific problems o! Ihe vehicle lor example the controls of diesel engines and hydraulic pumps is available to all workers They can communicate with the expen system via the underground diagnostic computer Special knowledge-bases serve to analyse the signals from high-pressure monitoring solid-bome noise measurement and non-contact torque monitoring On the basis of the machine history (administered by the expert system) weak points in machine maintenance use and construction can be meaningfully analysed

The fact that the implemented rules lake the instal lation date of the parts into consideration is important because technicians working on three different shifts often are not aware of work completed in pre vtous shifts and unnecessanly inspect parts oi sub svstems that have already been checked (Wisch newski et al IWS)

2 4 Interfile diagnostic systcm/MP(S

The diagnostic results are a need for maintenance work to be carried out This may be either a rcpan a service or a further detailed inspection I his requiiement triggers the activities supported bv the MPC S In order to lengthen the planning period and ıneıease the planning quality the information ıs auloıiidîıuıllv seul lo the MP(S as a rudimentary woik oidu

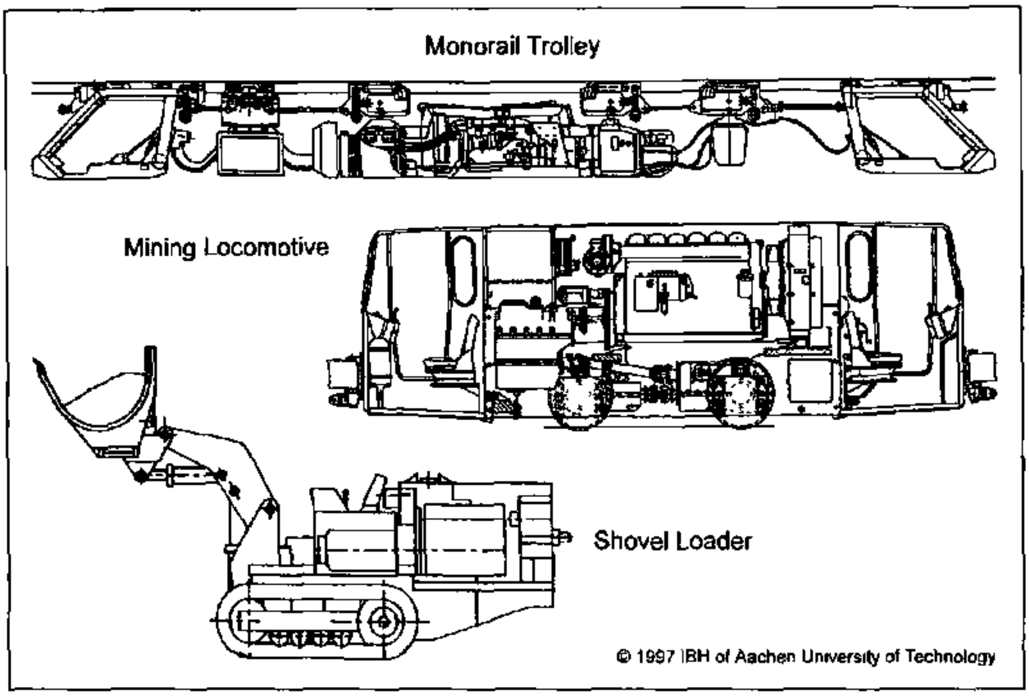

Fig 4 A selection of mining vehicles monitored by RUDI

containing -vehicle number, job plan number and priority The maintenance planner, using the MPCS, fills in the remaining work order information worker data, date and spare parts involved, and approves the work order The planned date and duration of maintenance are sent to the vehicle dispatching Using a common database for the expert system and the MPCS, redundancies and contradictions m data stocking are avoided Via a computer network, the approved work orders are passed on to the corresponding underground diagnostic computer, where they are indicated to the workers While carrying out the job. the worker can retrieve information from the MPCS about job plans or technical data about the vehicle Having completed the job, the worker uses the diagnostic computer directly for confirmation of the work order this is subsequently sent to the MPCS (Wischnewski et al. 1996)

3 ENGINE DIAGNOSTICS RESEARCH DUE TO THE DEMANDS OF SURFACE VEHICLES

Although meeting special requirements of vehicles in the underground mining (Fig 4), the presented system can be adapted for other industrial applications and some diagnostic modules have already been adapted for a surface application, namely a rail car on a private German rail company For further diversification into surface vehicles, for example heavy duty trucks in the mineral industry or cargo trucks, the engine diagnostic functions will become more important A comparison of the failure distribution of monorail diesel trolleys with the one produced by road cargo trucks (Dumoulin and Burgwinkel, I991) points out that the diesel engine is of major interest if no hydrostatic or hydrodynamic power transmission belongs to the vehicle (Fig S)

A technical argument for increasing importance of engine diagnostic methods is given by the fact, that most surface transport vehicles in the future will be equipped with supercharged diesel engines This is due to their better torque characteristics, their lower exhaust emissions and a better power-to-mass ratio compared to naturally aspirated diesel engines

There arc three main methods for supercharging of combustion engines, namely mechanical charging by compiessors, turbo-charging by e\hau->t-dnven superchargers and charging methods working without any compressor, foi example pressure wave chaigimi

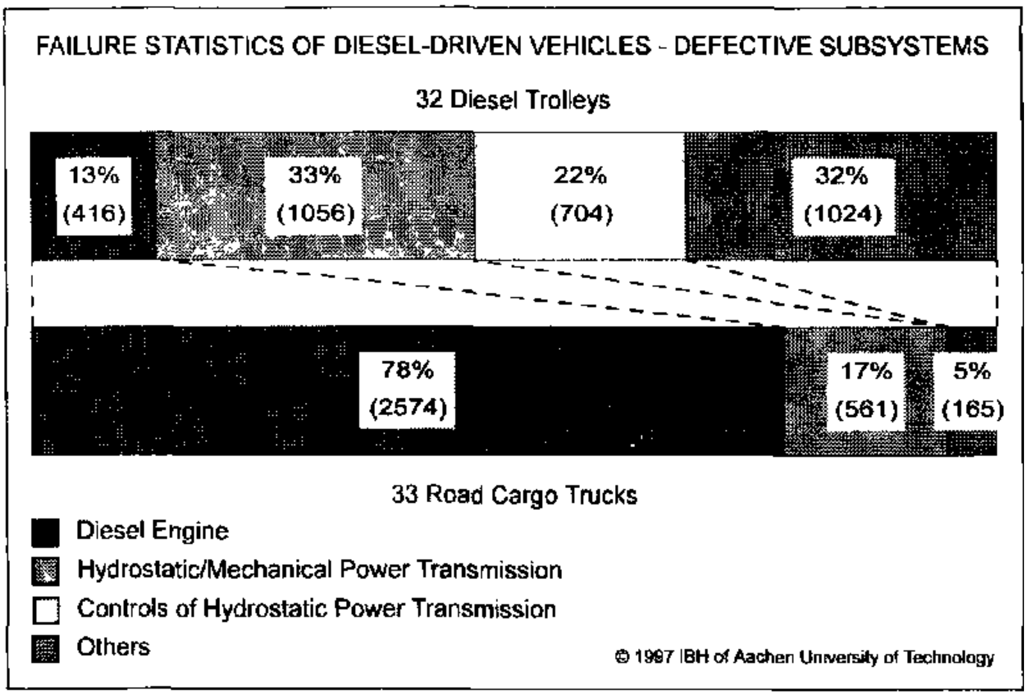

Fig 5 Comparison of failure distributions of different types of diesel-dnven transport vehicles.

(comprex method) and resonant charging Turbocharging is the most important one

Condition monitoring in general deals with the detection of a fault's kind and severity as well as the identification of the faulty component in a complex engine Reduced power of diesel engines is most often caused by compression faults, for example by maladjusted valve settings and worn piston rings, or malfunctioning components of the fuel miction system To detect these faults engine tests are usually ma<!e di. mg steady-stale operating modes - and so d .es RUDI compression faults aie delected by high .[•solution speed analysis dmmg cold lests Faults of the injection system aie Hacked by hot lests (idle speed) using high piessuie analysis and suitable diagnostic parameters based on high icsolution speed measurements To identify defective cylinders different cylmdei-specific paiamelers arc available, loi example the alternating amplitude of the gas toique (see u'Uioii 2 2) the velocity index or the accclerauni index Their common attribute is thai they aie '• "med for steady-stair opnating mode* of the engine

3 1 Experimental results from steady-state hot tests

Recent trials on a test stand with an impulse-charged V-6 diesel engine with intercoolmg proved that obstructive interactions - with regard to cylinder-specific evaluation of the engine's condition - between faulty and intact cylinders may occur Dunng tests when the engine was running at idle speed with a severe fault at a single cylinder (no fuel condition) an evaluation of the velocity index implied that there are two defect cylinders (Asch and Burgwinkel, 19%) However RUDI ıs able to identify the single faulty cylinder by means of high pressure analysis of the injection system.

These experiments demonstrate that diese! engines with exhausl-dnven supeichaiger, need more sophisticated methods for speed-based engine diagnosis during hot tests, because inlet and outlei system aie linked by the turbochargcr I'arlicuiarly those with impulse charging are more demanding with icgaid to cylinder-specific diagnosis because H cylinders pciformance may be influenced by anolhei one

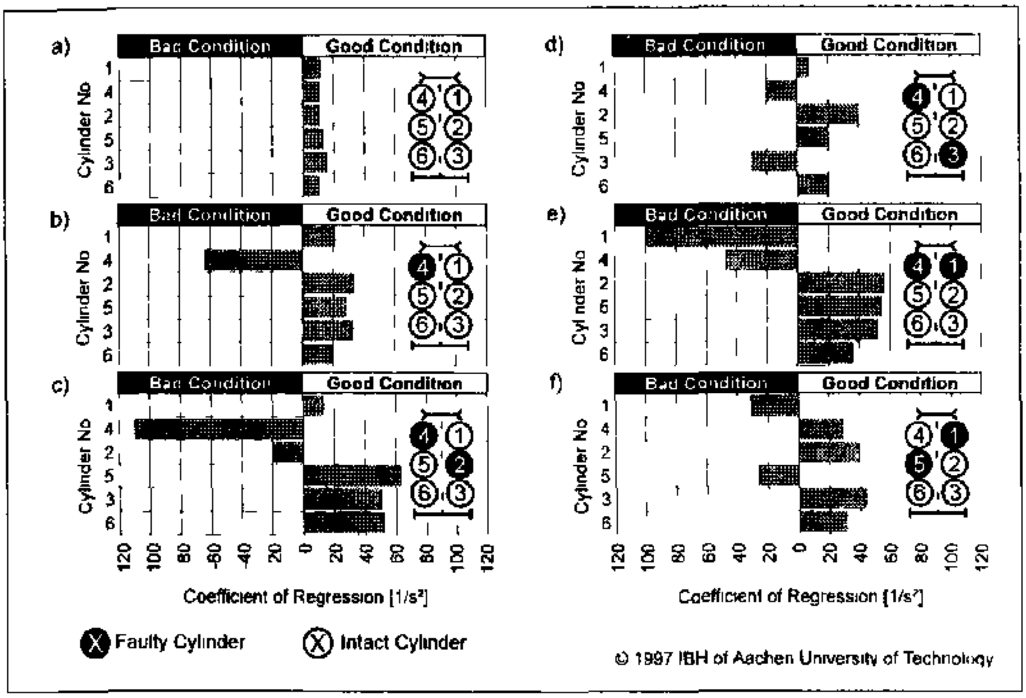

Fig 6 Cylinder-specific fault detection on an impulse-charged diesel engine by snap acoeleiahon tests

3 2 Experimental results from acceleration tests

Much better cylinder-specific fault detection with the impulse-charged diesel engine could be reached by performing snap acceleıalıon tests In free accelera-tion mode (no externa! load maximum tuel) the en-gine là run from idle to limn speed When the engine speed crosses a pre-defined inggei-level a high resolution speed medsui ement ıs caı ı u ' out

Speed data liom these tests aie evaluated as follows A window containing speed data of one cycle (two rotations on a 4-slroke-engme) is cut into z intervals where *i* represents the total numlxr of tyiuidus Lach interval consists of the expansion phase of a singk cylmdci and the compiession ph ise o! 1he H I M cylmdei tctcirin^ (o the filing sequence l-or tatlı interval the parameters of a regttssion line an calm lafed Intact cylinders have a positive slope of the le giession line wheieas negative slopes indicate faulty tylmdets Using fhis method positive lesults (! ıg n) woe gamed not only with single faulty cylmdus but also wilh dilleitnl combinations of faulty ı\lındcıs ("• at most)

1 1 Engine compression test for surface vehicles

Because of safety requirements diesel-driven under-ground vehicles in coal mining are equipped with pneumatic barters Diesel engines in sut face vthules have electric starters with D(slartmu motors l heir motor current Is close!v linkt d lo MIL slailmi' luiqui and easily to measinc by llall-cknuiils l hi-, qualifie, the motor (inien! loi dynamic compression lists (Kicriloif and kiswloil l'JSM l nils un llic l •(stand piovcd diagnosis based on mid it ı im ı uiements ol the motoi turren! to l« ol similar itli ability as il based on hii'h icoluiinn spttd IIIL,l inemtiits

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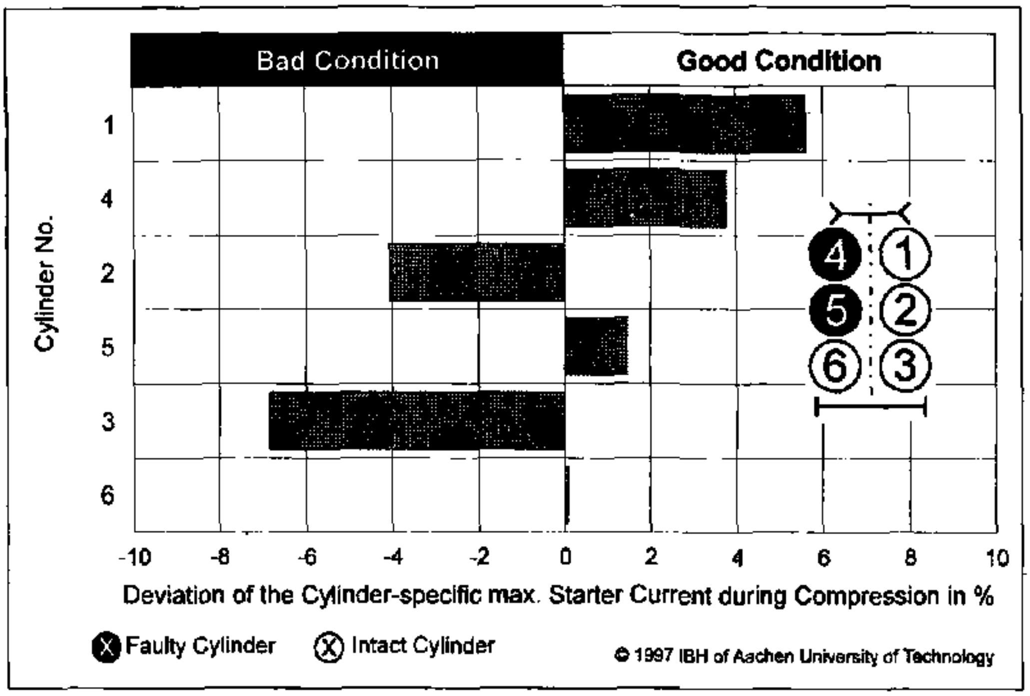

Fig 7 Cylinder-specific fault detection on multi-cylinder engine by evaluation of starter current.

able potentials for lowering of maintenance costs by a condition-based maintenance strategy To get the necessary information about the condition of a vehicle's most interesting subsystems, namely the diesel engine and the hydraulic power transmission, a modular vehicle diagnostic system has been developed, that is good for mining It supports the maintenance staff by offering diagnostic knowledge by an integrated expert system and by data exchange with a maintenance planning and control system

Although meeting the special requirements of transport vehicles in the coal mining, the presented system is principally capable to support equipment maintenance management and performance monitoring of all kinds of vehicles with diesel-hydraulic drives

Transfer of the system to surface vehicles means to diagnose turbocharged engines, which are due to their greater complexity more demanding concerning high resolution speed analysis than naturally aspirated diesel engines Experiments with a state of the art impulse-charged diesel engine proved that deterioration of cylinder-specific performance is more reliably detected during acceleration tests than during steady-state tests. Considering these results the diagnostic modules will be extended.

REFERENCES

Asch, A. and Burgwinkel, P. 1996 *An integrated monitoring and diagnostic system for diesel powered transport vehicles' in the mining industries.* Proc. MINMET '96 International Conference on Mining and Metallurgy in a Changing Environment: 43-49. Harare/Zimbabwe, University of Zimbabwe.

Dumoulin, L. and P. Burgwinkel 1993 *RUDI, an overall vehicle monitoring- and diagnosis system.* Proc TOOLDIAG '93 International Conference on Fault Diagnosis, 248-255. Toulouse/France.

Kierdorf, B and J. Kasedorf 1988. *Kfz-Motortest.* Würzburg, Vogel-Verlag.

Keßler, H -W. 1994. *Entwicklung und Untersuchung eines Diagnosesysiems zur Wälzlagerüberwachung hydrodynamischer Getriebe.* Aachen, Verlag der Augustinus-Buchhandlung.

Linnartz,A. and P Burgwinkel 1992. *Analyse und* ***Optimierung der Instandhaltung von Dieselkaisen.*** Glückauf 128 (2): 104-110. Essen, Glückauf-Verlag.

Seeliger, A. et ai. 1994. ***Neues Diagnosesystem fitr*** *Dieselkatzen*. Glückauf 130 (11) 697-703. Essen, Glückauf-Verlag.

StreIchfiiss, M 1993. ***Maschinendiagnose an diesel-getriebenen Transportfahrzeugen im deutschen Steinkohlenbergbau.*** Aachen, Verlag der Augustinus-Buchhandlung.

Wischnewski, R. et al. 1995. *A modular expert system/or* ***diagnosis of vehicles with Diesel hydraulic drive components used in the mining industry*** **Proc.** APCOMXXV International Symposium on the Application of Computers and Operations Research in the Mineral Industries 103-108 Brisbane/Australia AusIMM.

Wischnewski, R. and P. Burgwinkel 1996 *Embedding* ***of an expert system for diagnosis of dtesel-driven vehicles into the maintenance management*** *process*. Proc MPES '96 Fifth International Symposium on Mine Planning and Equipment Selection 587-591. Rotterdam. A A. Balkema Publishers.

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