Bohumil SKALA

MODE OF OPERATION OF A DRIVE MOTOR

ABSTRACT *Our department cooperates with the company on a squirrel cage asynchronous machine of a power 1 600 kW. This machine will be used for a new three-system railway locomotive which is designed for the Czech Railways. In this paper the typical mode of operation of a locomotive is analyzed. The aim is to determine the expected frequency of various modes of operation and choose the dangerous speed of a machine. This dangerous speed has to be skipped as fast as possible.*

Keywords: *traction motor, railway locomotive, dangerous speed*

1. INTRODUCTION

The asynchronous machine will be powered by a frequency converter. Due to this fact the supply voltage frequency could be the same as a short circuit ring natural frequency. In this case the rotor bars can break away from the ring in a very short time.

The locomotive has 4 asynchronous tractive machines with the squirrel cage rotor. Each machine has a power of 1600 kW. Up to now, it is the biggest power of an asynchronous machine, which is situated between rail axes of a size 1435 mm.

Bohumil SKALA, Doc. Ing. Ph.D
e-mail: skalab@kev.zcu.cz

Department of Elektromechanic and Power Electronic,
Faculty of Electrical Engineering,
University of West Bohemia in Pilsen,
Univerzitni 8, 306 12 Pilsen, Czech Republic

The squirrel cage rotor has a cooper winding which consists of bars and two short circuit rings. The bars and rings are brazed. Over both short circuit rings, shrung-on links are placed.

a) b)

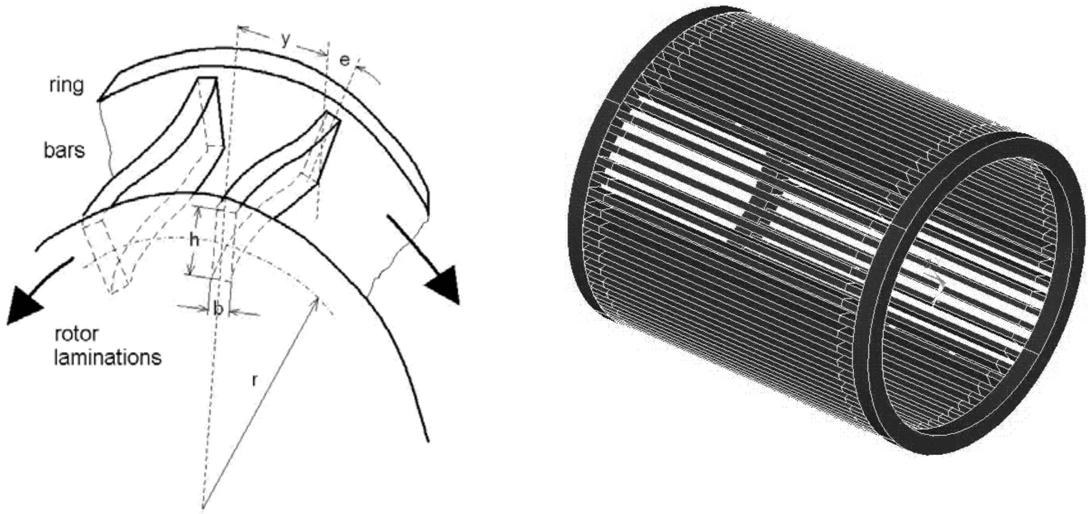


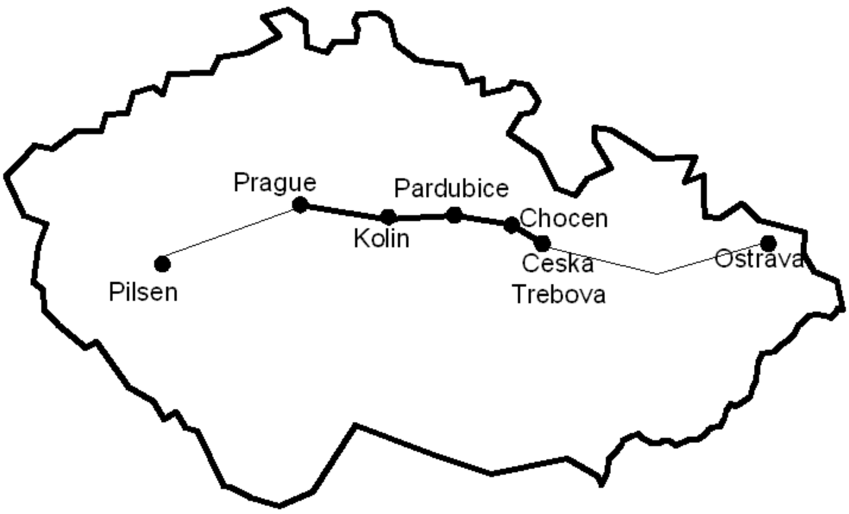
Fig. 1. (a) Deformations of the bars (b) Squirrel cage rotor winding, ANSYS model

Based on the practice of the company, fatigue failure occurs sometimes on the rotor bars, located near to the short circuited ring. The similar problem is being solved also by other companies, e.g. Alstom.

2. THE RAILWAY ROUTE PRAGUE – CESKA TREBOVA

This three-system locomotive will be operated mainly on Czech high speed corridors. For our purposes, the railway route from Prague to Ceska Trebova has been chosen. The data were obtained for passenger fast train of a total weight 450 t and a freight train of a total weight 1400 t. The length of the route is 165 km, maximum allowed speed is 160 km.h^{-1}. Both directions were observed. Both trains stopped only two times, in Kolin and Pardubice. The braking energy was recuperated back to the trolley line.

a)



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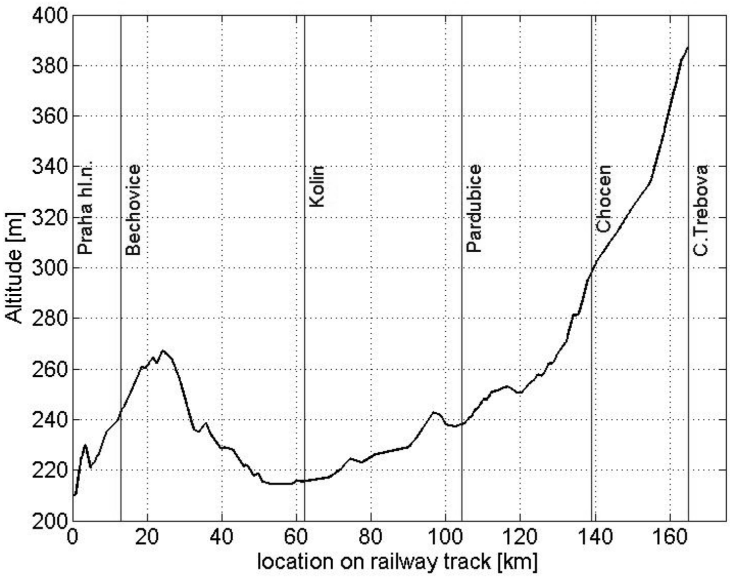

Fig. 2. (a) Czech republic and testing railway route location (b) Altitude

3. TRAIN SPEED AND THE MOTOR TORQUE

Train speed is given by several parameters. Firstly, it is the allowed ground speed. This is the speed the train can reach if its manufacturer's maximum speed is not lower. The train speed can be lower, when train just start up from the railway station or brake before the station. Gradient of the railway line is also very important. When the machine of the locomotive operates not with full power and simultaneously on a steady speed, the torque of the machine is proportional to the gradient of the railway line. When the train is under acceleration or deceleration, the torque of the machine and gradient of the railway line has the superposition. When the train accelerates and the railway upraises, or the train brakes and the railway drops, the torque of the machine reaches its positive or negative maximum.

At the maximum machine torque, the adhesive force has to be able to transfer the machine torque (or torque of the wheel) to the rail. If the rail is wet, icing or groove by the foliage, the adhesive force is strongly decreased and the axe can drive slip.

a) b)

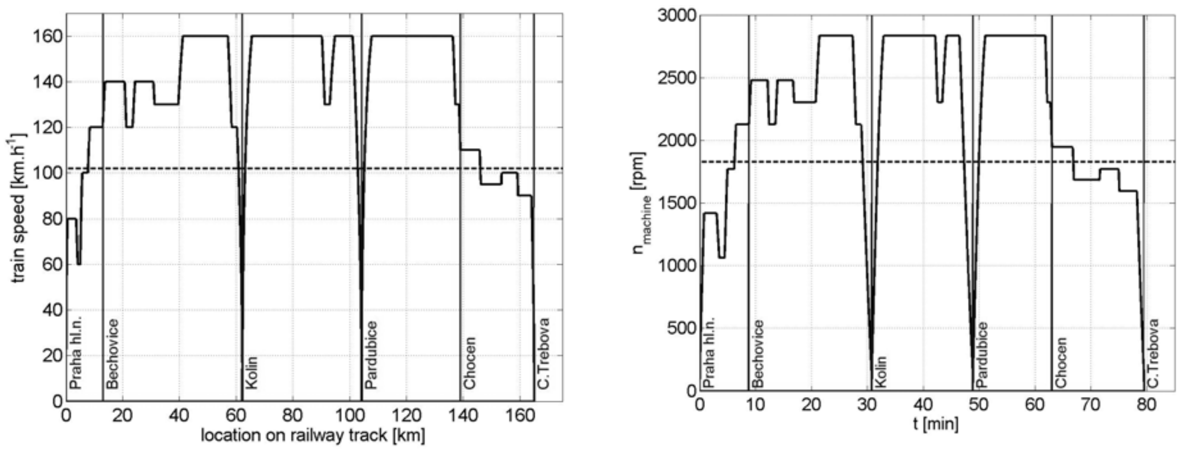

Fig. 3. Fast train in a direction from Prague. (a) Train speed. Nominal speed is 102 km.h^{-1} (b) Asynchronous motor speed. The nominal speed is 1828 rpm, f_n = 92 Hz

4. THE STEADY STATE TRAVEL, BRAKING AND RUN-UP

In the following figure we can see the detail of the braking and run-up. To easy follow the behavior, the area is divided to 5 zones.

At the beginning of the zone No.1, the train moves with the steady speed of 130 km.h^{-1}. The torque of the wheel 5 kNm is proportional to the gradient of the railway line and covers the mechanical losses of the train. Then the train increases the speed up to 160 km.h^{-1}. The torque jumps to 30 kNm. For the acceleration it is used the maximum power of the machine at this speed. Immediately, when the speed reaches the maximum (i.e.160 km.h^{-1}), the torque follows the gradient of the railway line only. This is the end of zone no.1.

a) b)

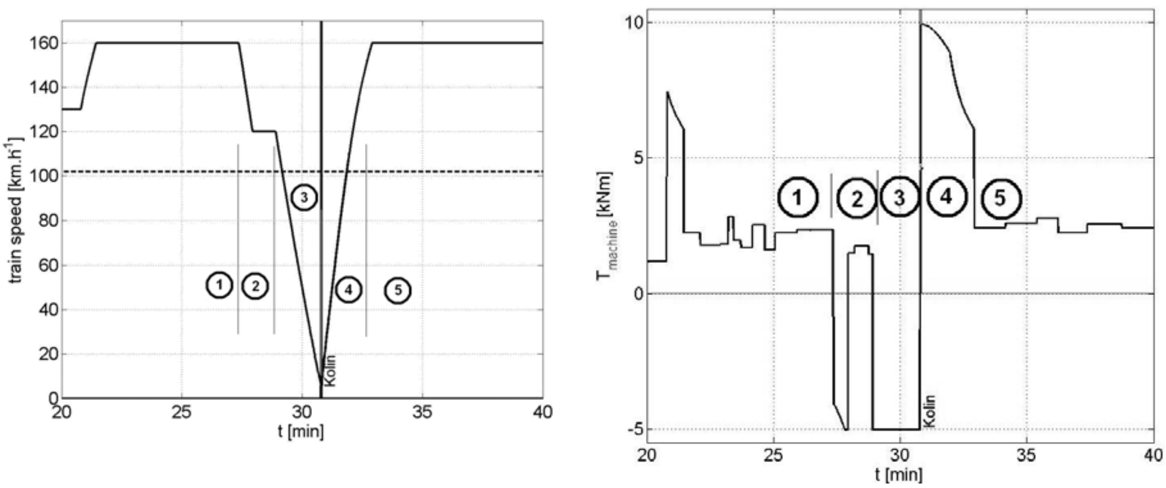

Fig. 4. Fast train in a direction from Prague. (a) Train speed before and after railway station Kolin. (b) Asynchronous motor torque

a) b)

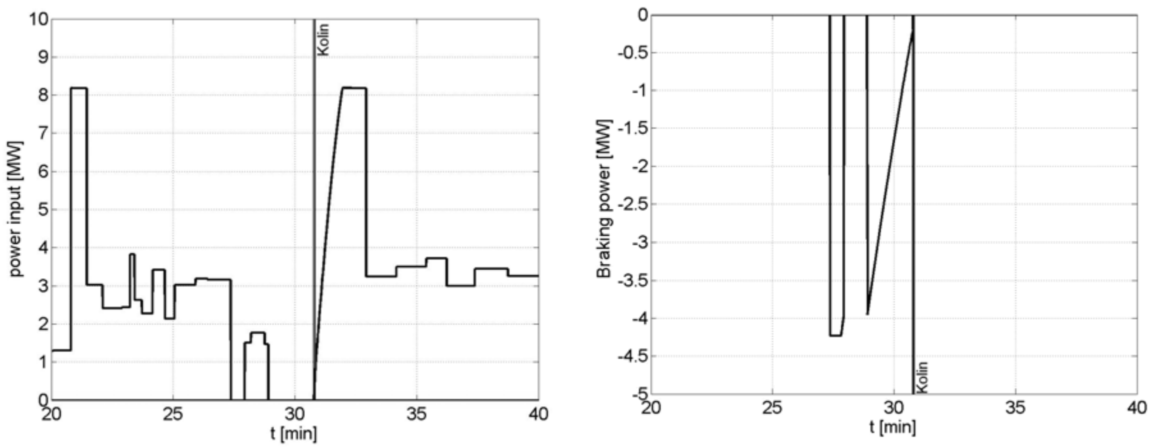

Fig. 5. Fast train in a direction from Prague (a) power input (b) power output, braking power (of an all locomotive, i.e.4x asynchronous machine)

Zone No. 2 starts by braking to the speed 120 km.h^{-1}. Due to this fact the torque is negative. At this speed the train drives through the switches points and at this speed the train approaches the platform.

Zone No. 3: Before reaching the platform, the speed is decreased to zero. For this purpose the time for exit and entrance of the passengers is zero.

Zone No. 4 is a run up to the traveling speed 160 km.h^{-1}. The torque should be the constant up to nominal speed of the machine (f = 92 Hz, machine speed = 1828 rpm, train speed = 102 km.h^{-1}), above this point the field weakening causes the decreasing of the torque. The details are shown on the following figure. The part labeled as A is for speed being lower than nominal, the part labeled as B is for speed above the nominal value.

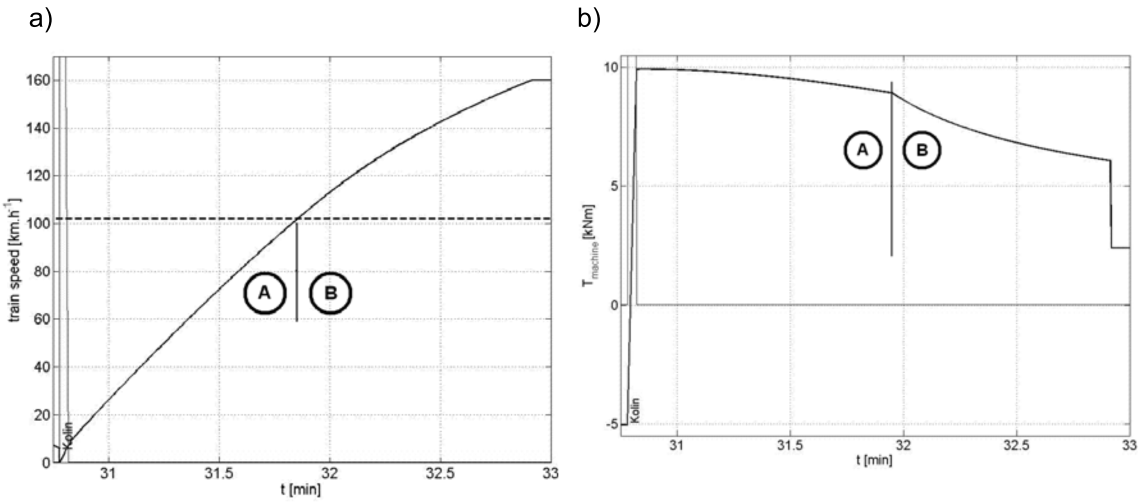

Fig. 6. Fast train in a direction from Prague. (a) Train speed after railway station Kolin (b) Asynchronous motor torque

The zone No. 5 is similar as a zone 1.

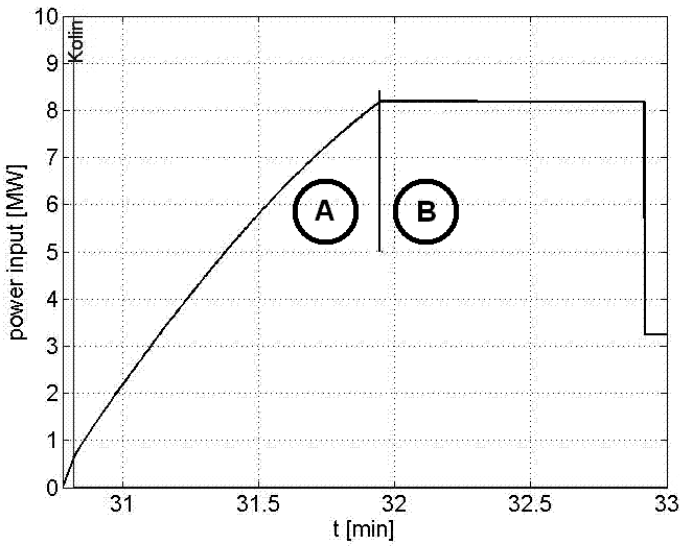

Fig. 7. Fast train in a direction from Prague, locomotive power input (4x asynchronous machine)

5. THE HISTOGRAMS

For the purpose of observing which values of speed are in operation most frequently, the histograms were used. The histograms are different for fast train and for goods train, of course. The train direction from Prague or to Prague has only a small influence to the histograms. As a contrast, the train direction has the impact to power consumption and travelling time.

a) b)

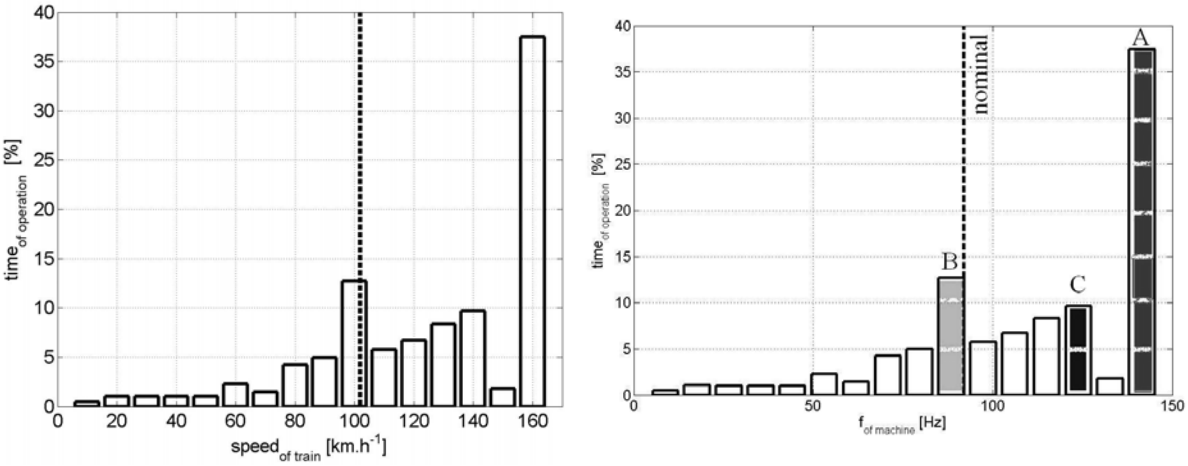

Fig. 8. Fast train in a direction From Prague. (a) Train speed histogram (b) The histogram of an asynchronous motor supplying frequency. The nominal is 92 Hz
A – 138,0-145,2 Hz (37,5%), 150-160 km.h^{-1}, B – 85,0-92,0 Hz (12,7%), 90-100 km.h^{-1}, C – 120,2-127,4 Hz (9,7%), 130-140 km.h^{-1}

a) b)

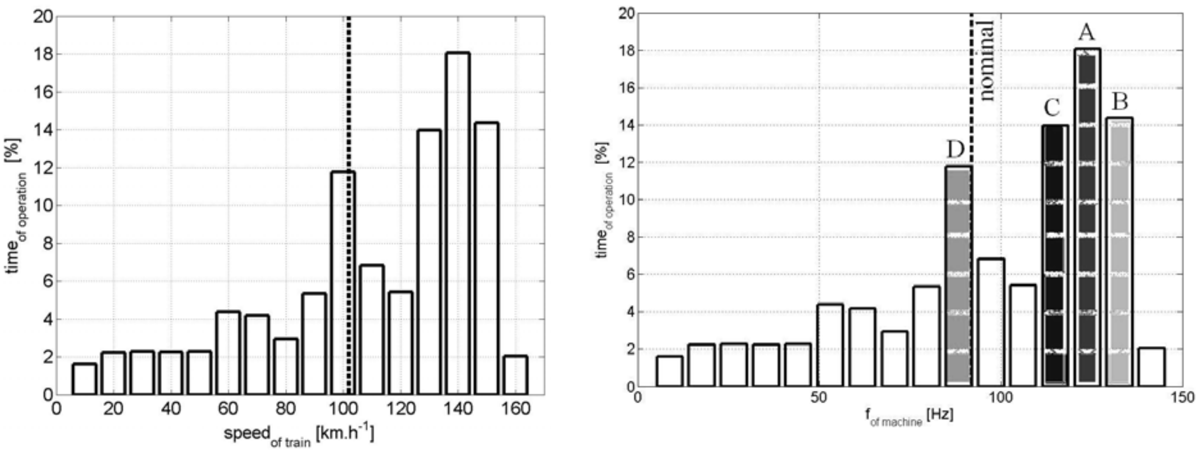

Fig. 9. Goods train in a direction from Prague. (a) Train speed histogram (b) The histogram of an asynchronous motor supplying frequency. The nominal is 92 Hz
A - 120,5-127,5 Hz (18,6%), 130-140 km.h^{-1}, B – 129,2 – 136,3 Hz (14,3%), 140-150 km.h^{-1}, C – 112,5-118,6 Hz (14%), 120-130 km.h^{-1}, D – 84,9 – 92,1 Hz (11,8%), 90-100 km.h^{-1}

6. Power consumption

Fast train in a direction from Prague

Power consumption	3 476 kWh
Braking energy	-379 kWh
Travelling time	79 min
Energy for one run-up	223 kWh

Fast train in a direction to Prague

Power consumption	2 816 kWh
Braking energy	-440 kWh
Travelling time	79 min
Energy for one run-up	223 kWh

Goods train in a direction from Prague

Power consumption	8 632 kWh
Braking energy	-575 kWh
Travelling time	94 min
Energy for one run-up	858 kWh

Goods train in a direction to Prague

Power consumption	7 157 kWh
Braking energy	-772 kWh
Travelling time	93 min
Energy for one run-up	858 kWh

6. CONCLUSION

In this paper the principle of fatigue failure of the rotor bars of a squirrel cage rotor of asynchronous machine is described. This problem is multitask and complicated, and due to this fact, the solving team consisting of several specialized workplaces was established. The close cooperation in the team is described.

The methodology for choosing the critical states is described. The real data from the railway truck from Prague to Česká Třebová was observed and analyzed. Based on this the critical mode of operation was chosen.

Acknowledgement

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TRYBY PRACY NAPĘDÓW SILNIKOWYCH

B. SKALA

STRESZCZENIE *Przedstawiono prace realizowane w Zakładzie Napędów Politechniki w Pilznie dotyczące napędów lokomotyw. We współpracy z zewnętrzną firmą opracowano i uruchomiono produkcję klatkowego silnika asynchronicznego o mocy 1600 kW. Silnik ten będzie wykorzystywany w trzech nowych systemach napędowych lokomotyw przeznaczonych dla Kolei Czeskich. Przedstawiono analizę trybów działania lokomotyw, której celem było ustalenie zagrożeń w poszczególnych trybach i określenie niebezpiecznych prędkości obrotowych. Pozwala to unikać tych prędkości przez lokomotywy zmniejszając w praktyce zagrożenie awarią silników.*