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A METHOD FOR ACCELERATED TESTING OF FARM MACHINERY

The obstacle proving-track for simulating the load under transportation of slow vehicles and trailed implements

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SUMMARY

A circular 87,5 metres long obstacle proving track has been constructed out concrete for the institute to accelerate the durability tests of vehicles and trailed implements. The profile of the track has been obtained through measuring and on the grounds of this the mean-square spectral density of the tracks profile has been computed. With the help of the mean-square spectral density the track can be compared with normal running surfaces. The track is established to be more uneven than regular roads and field surfaces. Only a hardend ploughed field driven across the furrows is noticeably more difficult than this track. A vertical exciting function can be subjected to the vehicles that are intended to be tested on the track. This vertical function is in most cases in resonance with the natural frequency of the vehicle. The critical travel speed falls usually to the velocity range of 1 . . . 3 m/s.

SELOSTE

Tutkimuslaitoksella on vuodesta 1965 lähtien ollut käytössä betonista rakennettu ympyrän muotoinen 87,5 m pitkä esterata. Rata on tarkoitettu pyörillä kulkevien ajoneuvojen ja työkoneiden kestävyyden selvittämisen jouduttamiseksi. Jotta radan aiheuttamaa kuormitusta voitaisiin verrata käytännön ajon aiheuttamaan kuormitukseen erilaisilla teillä ja pelloilla, on laskettu radan profiilin spektrin neliöllinen keskiarvo. Radan profiilikäyrä on määritetty ajoraiteiden kohdalta mittaamalla poikkeamat vaakasuorasta 0-tasosta 15 cm välein. Kuten jo silmävaraisesti voidaan arvioida, rata on tavanomaisia ajoteitä sekä yleensä myös pellon pintaa epätasaisempi. Ainoastaan kovettunut kynnöspelto poikkiviilujen ajettuna on selvästi tätä rataa vaikeampi. Radalla voidaan kohdistaa tutkittaviin ajoneuvoihin ja työkoneisiin pakkoliike, joka sattuu resonanssiin ajoneuvon ominaistaajuuden kanssa. Kriitillinen ajonopeus on useimmiten nopeusalueella 1 . . . 3 m/s.

Rata on osoittautunut erittäin käyttökelpoiseksi mm. traktorin perävaunun vetokoukun kokeilun kiihdyttämisessä. Perävaunun aisa kuormittaa vetokoukkua suurimmalla mahdollisella tieliikenneasetuksen sallimalla kuormituksella. Ajonopeutena on tällöin voitu käyttää vain n. 0,6 m/s. Jo 30 tunnin ajo radalla on osoittautunut riittäväksi.

CONTENTS

1. Foreword

To day the time used to develop a new machine is aimed to be as short as possible. The machine must, however, be ready when it is marketed, in other words it has to operate with reliability and in proposed way in practice. A result like this is obtained only through tests carried out in correct manner.

Devices, which simulate conditions in practice and where the machine can be run under intensified load, are often used to shorten the period of testing. An accelerated testing can be obtained in many different ways:

1. The running of the machine is automatized in such a way that it can run almost day and night, under as normal conditions as possible and at the same time being controlled by measuring and recording devices. The automatization of loading and controlling can be carried out to various degrees.
2. The load is increased in such a manner, that weak points and possible wear and tear are noticed in a relatively short period of time.
3. The frequency of load application is increased.

However, when the latter two methods are used, one has to be aware of how the intensified load will correspond to the load in practice. Certain allowances have to be made especially in regard to increasing the stress amplitude and mean stress. At any rate the load collective of a dynamically loaded machine should in the accelerated tests correspond to the load collective in practice as closely as possible.

2. Accelerated testing on the obstacle proving-track

Testing of vehicles, trailed implements, frame of tractor mounted implements etc. can be accelerated by running them on a track, on the surface of which elevations and pits have been made in such a way that the vehicle or implement is subjected to a continuously varying load.

The accelerated testing track of the institute is seen in figure 1. The track is made out of concrete. It is 87,5 metres long. The larger obstacles, 16 in number, are removable. The smaller uneventies 53 . . . 56 centimetres apart and 2 . . . 3 centimetres high are fixed.

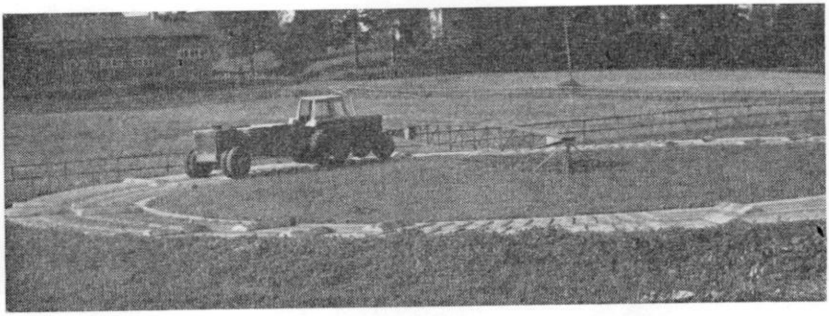

Fig. 1. The accelerated testing track of the institute.

The magnitude of load is influenced by the following factors

a) weight of the vehicle and the size of the load it is carrying,

b) the properties of the track surface,

c) stiffness and damping of the vehicle (the vibrational characteristics of the system) and

d) travel speed.

One difficulty in accelerated tests on the proving track is the reduction of the frequency of small acceleration amplitudes compared to running in practice. This is due to the difficulty in increasing the frequency of oscillation of the vehicle above its natural frequency [3].

The omission of the smaller stress amplitudes will introduce an error when the testing on the track is criticized especially as for parts of vehicle which are subjected to a high mean stress as well as the varying cyclic load. Even small cyclic stresses for these parts may exceed the endurance limit and will contribute to the eventual failure of that part. Due to this these parts fail in the accelerated test prematurely, thus indicating a shorter lifetime than in practice. Instead parts with low mean stress are not affected in this manner in accelerated tests, because small cyclic stresses remain below the endurance limit.

By running the vehicle under normal conditions for part of the testing period the error caused by omitting small stress amplitudes can be avoided. In this way the lifetime of parts which are subjected to a high mean stress can be obtained with sufficient reliability. It must be noticed that the greater the test's »acceleration factor» is the longer the field trials have to be. If the »acceleration factor» is 4 . . . 5 the field trials have to be about half the machine's desired lifetime. Increasing of the »acceleration factor» promotes reliability, but may lead to a design that is conservative.

A similar accelerated test can be achieved through »running» the machine on rolling drums, on the surface of which different kinds of elevations have been fixed. This kind of method leads, however, to a notably more one-sided way of loading than the above mentioned track, because the circumference of the drum can hardly be more than about 6 metres. On the other hand the automatization is easier to arrange, and the test is not dependent on weather.

The perfect method in this respect is one where the wheels of the vehicle are placed on platforms that move up and down hydraulically and are excited, during playback, by observation material from practice on a tape-recorder tape.

To make it possible to compare the load on proving track with the load in practice the track's difficulty, (shape and size of irregularities of surface) compared to various surfaces of roads and fields in practice, has to be known. The running surfaces in practice can be considered as random functions in regard to shape and size of irregularities. For this reason, when the proving tracks are being planned, one should aim at a continuous varying cyclic load applied at random, in which the most common special cases in practice would be included, such as obstacles that stretch across the whole road and obstacles in waves of various length taking turns on both tracks.

3. Computing of the mean-square spectral density of the track profile [1]

Degrees in difficulty of this kind of stochastic surfaces can best be compared by computing the mean-square spectral density of the profile of the surfaces. If a continuous sample is taken of the vertical varying of the track's surface $f(x)$ the mean-square

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[1] Acknowledgement — The author is grateful to Mr P. Hannukainen and Mr K. Helander who set up the program and carried out the computations.

spectral density of the track profile is defined according to MITSCHKE [4] as follows:

$$\Phi\,(\Omega) = \frac{\lim}{x \rightarrow \infty}\,\frac{1}{2\,\pi\,X}\left[\int_{-X}^{+X} f\,(x)\,e^{-i\,\Omega\,x}\,dx\right]^{2} \tag{1}$$

where Ω = profile frequency of the track [m^{-1}]
X = limits of integration
i = imaginary factor
e = base of natural logarithms

Because the samples of the track were not taken continuously, but at equally spaced intervals, the mean-square spectral density was not computed directly from formula (1). In that case uneventies under a certain limit were not taken into account. The distance between measured profile points was, however, made so small ($\Delta\,x$ = 15 cm) that the uneventies excluded have no effect in regard to loading. The profile of the surface was measured along a marked circumference using a measuring stick, whose spherical base was 10 cm in diameter. The vertical position of the stick in regard to horizontal 0-level was read from a theodolite.

In figure 2 one can see the measured track profiles while the track width was 1,45 metres. The proving track is a little tilted, consequently it includes among other things a wave whose length is the same as that of the whole track. It is clear that a wave of this kind has no significance in regard to the vehicles vertical loads.

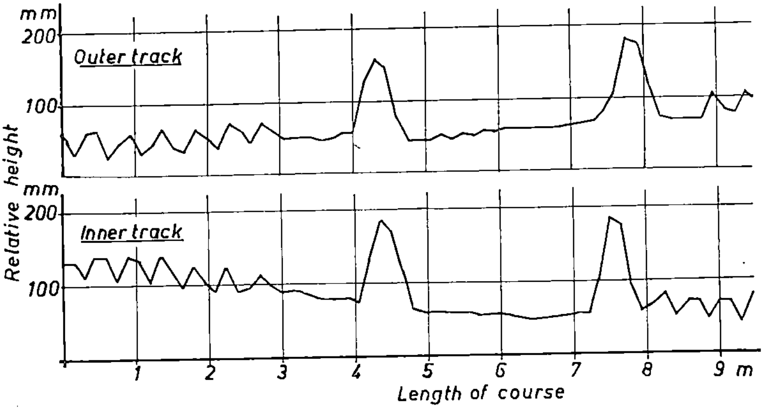

Fig. 2. A sample of the profile of the proving track on grounds of measurements made at 15 cm intervals.

To eliminate long waves (for example a wave length of 10 metres) average values were formed

$$f_{\bar{m}}(x) = \frac{1}{1+l} \sum_{k=-l/2}^{k=+l/2} f(x + k\,\Delta x) \qquad (2)$$

where l stands for the number of steps (Δx) on the observed distance.

Profile height is established as a deviation from this average value

$$\bar{f}(x) = f(x) - f_{\bar{m}}(x) \qquad (3)$$

To obtain the mean-square spectral density of the track's profile an autocorrelation factor was first computed for it [2]

$$R_r = \frac{1}{n-r} \sum_{p=1}^{n-r} \bar{f}(x=p)\,\bar{f}(x=p+r) \qquad (4)$$

where $r = 0, 1, 2 \ldots m$ and $n =$ the total number of measuring points. m was chosen to be so great $= 22$, that the longest wave that had importance on the vehicle's dynamic load was taken into account.

The mean square deviation of the profile function is obtained when $r = 0$.

$$R_o = \sigma^2 = \frac{1}{n} \sum_{p=1}^{n} \bar{f}^{2}(x=p) \qquad (5)$$

Autocorrelation factors form the periodic function, whose FOURIER-transforms represent the mean-square spectral densities Φ'_r of definite frequency ranges.

$$\Phi'_r = \frac{\Delta x}{\pi} \left(R_o + 2 \sum_{q=1}^{m-1} R_q \cos \frac{q\,r\,\pi}{m} + R_m \cos r\,\pi \right) \qquad (6)$$

The values of Φ'_r include side lobes due to the way of computing. These side lobes can be eliminated in the following way while the function will also be smoothed.

$$\begin{aligned} \Phi_o &= 0{,}54\,\Phi'_o + 0{,}46\,\Phi'_1 \\ \Phi_r &= 0{,}23\,\Phi'_{r-1} + 0{,}54\,\Phi'_r + 0{,}23\,\Phi'_{r+1} \\ \Phi_m &= 0{,}46\,\Phi'_{m-1} + 0{,}54\,\Phi'_m \end{aligned} \qquad (7)$$

Each of the Φ_r values corresponds to the average profile frequency

$$\Omega_r = \frac{r \pi}{m \Delta x} \tag{8}$$

Frequency can be defined for the range

$$\frac{(r - 1) \pi}{m \Delta x} \leqq \Omega_r \leqq \frac{(r + 1) \pi}{m \Delta x} \tag{9}$$

The selection of the quantities used in the above mentioned equations Δx (step length), m (number of autocorrelation factors) and $L = l\Delta x$ (length of track from which average value $f_{\overline{m}}$ has been computed) naturally has an effect on the results. The following principles were used when the quantities were selected:

Step length Δx limits, according to formula (8), the highest frequency whose mean-square spectral density is obtainable. As a principle must here be considered the fact that in computing so high frequencies can be taken into account, which correspond at least to the natural frequency when one is driving on the track at a normal velocity. The step length used can be made to correspond to the profile frequency

$F_{max} = 3{,}3\ [2\pi m]^{-1}$ and similarly the exciting frequency
$f_{max} = 3{,}3$ Hz at the velocity of 1 m/s and
$f_{max} = 13{,}2$ Hz at the velocity of 4 m/s.

Most of the natural vibration of the vehicles being tested on the track takes place at around 4 Hz, so that the velocity must be at least 1,3 m/s.

The number of the autocorrelation factors m limits the lowest profile frequency (the longest wave) that is obtainable in accordance to formula (8). Distance L, where the average value $f_{\overline{m}}$ is computed from, has to be naturally longer than $m\ \Delta x$. $m = 22$ used in this problem corresponds the profile frequency (the longest wave), which was obtained

$F_{min} = 0{,}1515\ [2\pi m]^{-1}$

When the track is driven at a velocity of 1 m/s the profile frequency corresponds to exciting frequency $f_{min} = 0{,}152$ Hz and respectively at a velocity of 4 m/s $f_{min} = 0{,}605$ Hz. Both of these frequencies clearly pass below the natural frequency of the vehicles tested on the track.

The length of the track (outer track 92 metres and inner track 83 metres) allows a sufficient number of measured values for computing. The computing was carried out in three parts. The final mean-square spectral density of the track is put forward as an arithmetic mean of the three parts, counting both tracks separately.

The autocorrelation function obtained through computing is seen in figure 3.

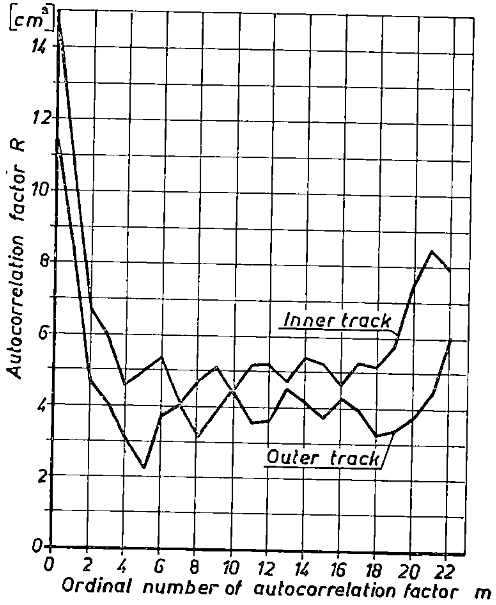

Fig. 3. The autocorrelation function of the proving track's profile.

In figure 4 is seen the mean-square spectral density of profile frequency of the institute's accelerated testing track compared to results that Wendenborn and some other researchers [5] have obtained of normal driving tracks. On the grounds of these one is able to compare the difficulty of the proving track with driving tracks in practice.

It can roughly be said that the track is more difficult than driving tracks in general. On the grounds of the compared mean-square spectral densities only driving on a hardened ploughed field across the furrows surpasses the difficulty of the proving track.

This is due above all to the 50 . . . 55 cm long profile waves on the track, the total height of which is 2 . . . 3 cm.

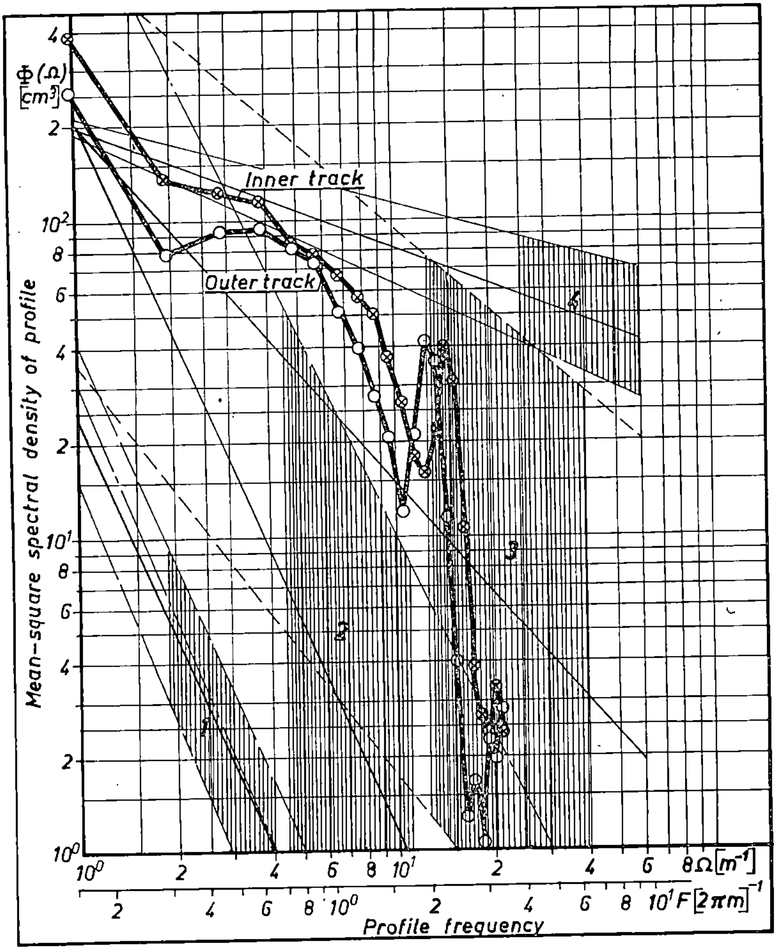

Fig. 4. Institute's accelerated testing track's mean-square spectral density of profile frequency compared to running tracks in practice.

1. First class asphalt road.
2. Dirt road.
3. Field with periodicity.
4. Ploughed field tractor driven across the furrows.

While the profile of the driving surface is usually stochastic, its mean-square spectral density of profile frequency can at least approximately be represented on log-log paper by the straight line

$$\log \Phi (F) = a \log F + b \text{ or}$$

$$\Phi (F) = 10^b F^a$$

In the equations a stands for the slope of the line and b the position of the line on the log-log paper.

This way of presentation makes the comparison of different tracks easier. The mean-square spectral density of the institute's proving track is obtained from the equation

$$\Phi (F) = 10^{1,55} F^{-1,22}.$$

In fact though the peak in mean-square spectral density of profile frequency ($F = 2{,}13 \ldots 2{,}28$ [2πm]$^{-1}$) due to the track's periodicity clearly deviates from this line. On driving tracks in practice $a = -2{,}53 \ldots -0{,}38$ and $b = -0{,}48 \ldots +2{,}00$.

The average acceleration is then unaffected by speed, when the slope of the graph, representing the mean-square spectral density, is $a = -1$ and directly proportional to the speed when $a = -3$.

4. The reciprocal influence of the track's surface profile and the vibrational characteritics of the vehicle

The following two facts have to be known in accounting for the accelerations and strains caused by the proving track or in prejudging the influence of the proving track on a vehicle which is only being planned:

1) The mean-square spectral density of the proving track.
2) The vibrational characteristics of the vehicle.

The mean-square spectral density of the proving track can be computed as before has been put forward, as a function of the profile frequency which reflects the influence of the track surface.

When the profile frequency is Ω a time (running velocity) dependent exciting frequency ω is obtained through the formula (10) when the running velocity is v.

$$\omega = v\Phi \qquad (10)$$

The graph representing the intensity of the exciting function is dependent on the mean-square spectral density of the profile frequency and on running velocity in the following way:

$$\Phi (\omega) = \frac{1}{v} \Phi (\Omega) \qquad (11)$$

Thus for each running velocity a graph of the intensity of the exciting function is obtained, figure 5.

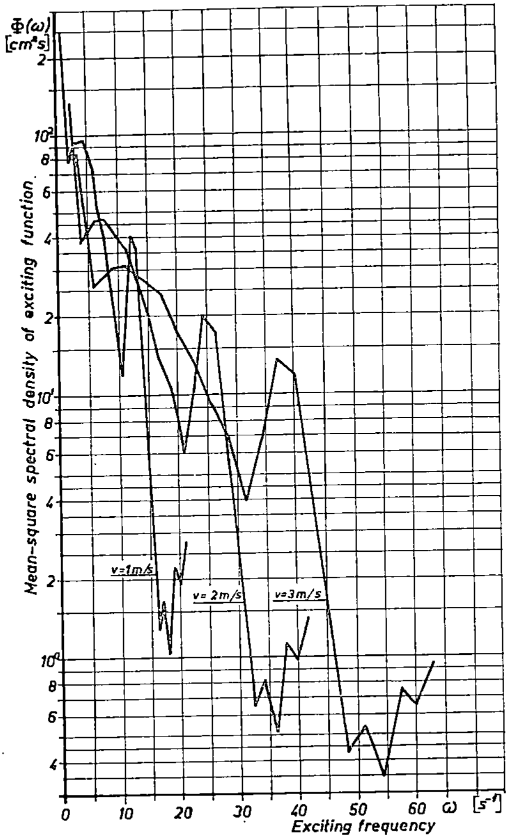

Fig. 5. The mean-square spectral density of the exciting function on the outer track as a function of the exciting frequency ω, when the running velocity is $v = 1$, 2 and 3 m/s.

The amplification factor S^2 describes the vibrational characteristics of the vehicle. The factor can be obtained empirically or through computing for different frequencies, figure 6.

The load of the vehicle (vertical acceleration and dynamic forces and moments corresponding to it) on the proving track is described by a graph, which is obtained by multiplying the values of the mean-square spectral density respecting each frequency of the exciting function ω by the values of the amplification factor S^2 corresponding to the same frequency, figure 7 [1]. On the other hand by measuring the load of the vehicle on the track values respective of that are obtained.

The amplification factor can be considerably altered, when necessary, by adjusting the vehicle's tyre pressure. In this way running on the proving track is made to correspond to a certain running in practice.

From graphs similar to those in figure 7 one can obtain some important rating factors:

1) The mean-square of the acceleration on various frequencies.

2) The area under the curve whose physical meaning is the mean acceleration of the vehicle.

3) An illustration on the fact which frequencies are more often represented and which occur seldom.

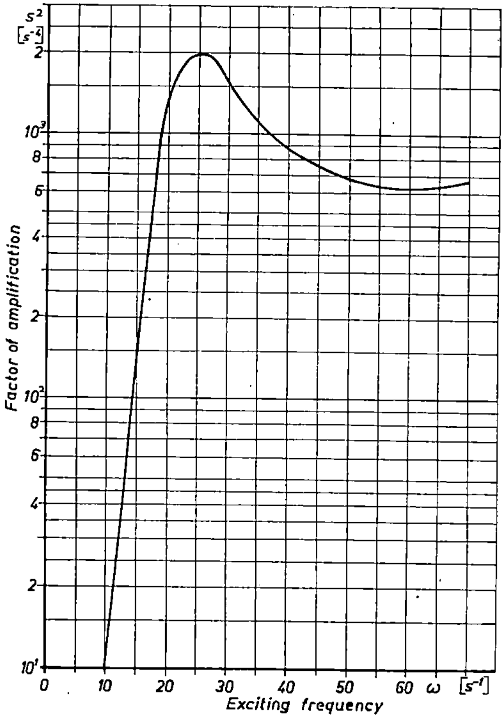

Fig. 6. The correlation of the amplification factor S^2 on the frequency of the exciting function. The case in the example deals with a one-mass system, whose natural frequency $\nu = 4$ Hz and damping ratio $k/k_k = 0{,}2$.

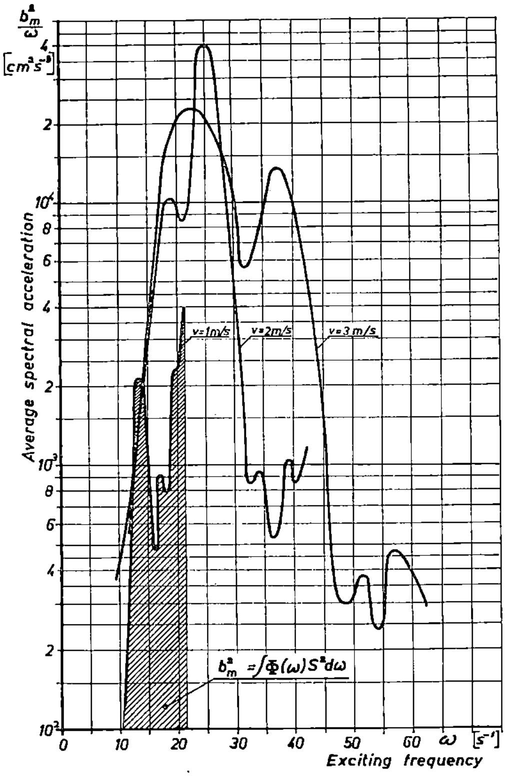

Fig. 7. Average spectral acceleration b_m as a function of the exciting frequency ω, when the running velocity is $v = 1$, 2 and 3 m/s and the vehicle is approximated with the same one-mass system as mentioned in figure 6.

5. On the use of the proving-track

The accelerated testing track of the institute has been in use since the year 1965. The track is designed for accelerated testing corresponding to load under trasportation of agricultural and forestry tractors and trailers and mounted implements used in connexion to them. One can respectively load some motor-driven machines on the track such as harvesters etc.

The track has proved to be very useful in accelerating the testing of a tractor trailer's hitch-hook. The boom of the trailer loads the hitch-hook with the maximum load allowed by the traffic code. In this case a driving speed of only about 0,6 m/s can be used. Already a running of 30 hours on the track has proved to be sufficient. So far 80 hitch-hooks have been tested on the track in this way.

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