

The influence of the carriage speed speed on the compliance of the tool-holder

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samenvatting

Summary

The effect of the motion of the carriage at the compliance of the Peter - Vanherck test rig has been measured for several conditions. A qualitative explanation of the phenomenon is given.

Actually this explanation is based on the results of analogue computer experiments.

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Introduction.

Displacement measurement of the test-rig and of the carriage as well are carried out during harmonic excitation of the test-rig.

With the aid of the results of these measurements some conclusions are made.

These conclusions lead to a simple mathematical model, which has been investigated on analogue computer.

The computer results are compared with the original experimental data.

1. Experiments.

1.1. Program of Measurements

The following measurements are carried out. See Fig. 1.

- a) The modulus of the transferfunction $\frac{x-y}{P}$ (strain gauges measurement) at $v = 0$ and $v = 200 \mu\text{m/s}$. for three values of the damping ratio of the testrig viz. Case I, Case II and Case III. See Figs. 2, 3, and 4.
- b) The amplitude ratio $|\frac{x-y}{P}|_{f_0}$ measured at natural frequency of the testrig ($\approx 155 \text{ Hz}$) as a function of the carriage speed also for the three cases mentioned. See Fig. 5.
- c) The absolute amplitude $|x|$ measured at natural frequency for $v = 0$ and $v = 200 \mu\text{m/s}$. also for the cases I, II, and III. See Table I.
- d) The absolute amplitude $|y|$ measured at natural frequency for $v = 0$ and $v = 200 \mu\text{m/s}$. also for the three cases. See Table I.

1.2. Remarks

- a) A comparison of absolute motion $|x|$ and the relative motion $x-y$ shows a same tendency with respect to decrease of the amplitude. See Table I and the Figs. 2, 3, and 4.
- b) The frequency at which the maximum amplitude of $|\frac{x-y}{p}|$ occurs (about natural frequency) does not change with a varying carriage speed. See Figs. 2, 3, and 4.
- c) The low frequency compliance (≈ 40 Hz) is not influenced by a change in the carriage speed. See Figs. 2, 3, and 4.
- d) An increase of carriage speed V results in a decrease of the test-rig motion x and at the same time an increase of the carriage motion y . See Table I.

1.3. Notes

- a) The in Table I mentioned y data for $v = 0$ are measured in an absolute way. As a matter of fact, there is no relative motion between carriage and frame in this case.
- b) However, at $v = 200 \mu\text{m/s}$. the frame movement is close to zero, so that the absolute movement y equals the relative displacement between bed and carriage.

1.4. Conclusions

The movement of the carriage influences the coupling of carriage and frame.

- $v = 0$. The harmonic forces between carriage and frame are not large enough to exceed Coulomb-friction forces in order to cause a relative displacement y between carriage and frame.

The coupling between the carriage and frame is rigid. See Note 1.3.a.

- $v = \text{large}$. Now, we have to deal with a relative velocity between carriage and frame. The Coulomb-friction transforms into a viscous friction. The coupling between carriage and frame is viscous and almost independent on the carriage speed. *)
See Note 1.3.b.

- $v = \text{small}$. The velocity amplitude of the carriage is equal or larger than the nominal speed V .

In this case the carriage will periodically stand still.

The coupling between carriage and frame is periodically rigid and viscous, and depends upon the carriage speed.

So we can divide the velocity range in two parts. See Fig. 5.

In the following the situation of a very loose and a rigid coupling of carriage and frame is simulated by varying the quantity ρ_y . This quantity represents the viscous friction between carriage and frame.

*) The viscous coupling between carriage and frame is also independent on the preload. That is the reason why the dynamic behaviour will not be influenced by locking the carriage at a certain speed.

2. Mathematical Model.

2.1. Differential equations

In the following part a very simplified model of the combination test rig-carriage-frame is formulated.

There are two simultaneous differential equations which describe the displacements x and y.

The solution of these equations is formed with the aid of an analogue computer.

$$m_x \ddot{x} + \rho_x (\dot{x} - \dot{y}) + c_x (x - y) = P$$

$$\rho_x (\dot{x} - \dot{y}) + c_x (x - y) = m_y \ddot{y} + \rho_y \dot{y}$$

where

m_x mass of the testrig

m_y mass of the carriage

ρ_x damping constant of the test rig

ρ_y damping constant between carriage and bed

c_x stiffness of the testrig.

See Fig. 1.

Substitute of

$$\omega_x^2 = \frac{c_x}{m_x}, \quad \rho_x = \frac{2\beta_x c_x}{\omega_x}, \quad \rho_y = \frac{2\beta_y c_x}{\omega_x}$$

and

$$\frac{m_x}{m_y} = k_m \quad \text{where}$$

β_x damping ratio of the test rig,

β_y reduced damping ratio of the carriage,

gives

$$\frac{1}{\omega_x^2} \ddot{x} + \frac{2\beta_x}{\omega_x} (\dot{x}-\dot{y}) + (x-y) = \frac{P}{c_x} \quad \text{and}$$

$$\frac{2\beta_x}{\omega_x} (\dot{x}-\dot{y}) + (x-y) = \frac{1}{\omega_x^2 k_m} \ddot{y} + \frac{2\beta_y}{\omega_x} \dot{y}$$

2.2. Dimensionless Computer Equations

The quantities, $x, \dot{x}, \ddot{x}, y, \dot{y}$ and \ddot{y} are related to their maximum values, $x_m, \dot{x}_m, \ddot{x}_m, y_m, \dot{y}_m$ and \ddot{y}_m respectively.

In case of an harmonic excitation, with the maximum circular frequency ω_{max} , the following relation between these maximum values will exist:

$$\begin{aligned} \dot{x}_m &= \omega_{max} x_m & \dot{y}_m &= \omega_{max} y_m \\ \ddot{x}_m &= \omega_{max}^2 x_m & \ddot{y}_m &= \omega_{max}^2 y_m \end{aligned}$$

Let us assume $x_m = y_m$.

Now the eqs modify into:

$$\left(\frac{\ddot{x}}{\ddot{x}_m}\right) = \frac{P}{c_x x_m} \left(\frac{\omega_x}{\omega_{max}}\right)^2 - \left\{ 2\beta_x \left(\frac{\omega_x}{\omega_{max}}\right) \left[\left(\frac{\dot{x}}{\dot{x}_m}\right) - \left(\frac{\dot{y}}{\dot{y}_m}\right)\right] + \left(\frac{\omega_x}{\omega_{max}}\right)^2 \left[\left(\frac{x}{x_m}\right) - \left(\frac{y}{y_m}\right)\right] \right\}$$

and

$$\left(\frac{\ddot{y}}{\ddot{y}_m}\right) = k_m \left\{ 2\beta_x \left(\frac{\omega_x}{\omega_{max}}\right) \left[\left(\frac{\dot{x}}{\dot{x}_m}\right) - \left(\frac{\dot{y}}{\dot{y}_m}\right)\right] + \left(\frac{\omega_x}{\omega_{max}}\right)^2 \left[\left(\frac{x}{x_m}\right) - \left(\frac{y}{y_m}\right)\right] \right\} - 2\beta_y k_m \left(\frac{\omega_x}{\omega_{max}}\right) \left(\frac{\dot{y}}{\dot{y}_m}\right)$$

The analogue computer circuit is given in Fig. 6.

2.3. Analogue Experiment

Most of the parameters of both eqs are known except the value of β_y .

We assume $\frac{\omega_x}{\omega_{\max}} = 0,5$, $k_m = 0,16$, $\beta_y = 10$ and $\beta_y = 3$.

2.4. Program of Measurements

The following measurements are carried out:

The modulus of the transferfunction $\frac{x-y}{P}$ for $\beta_y = 10$ and $\beta_y = 3$ for three values of β_x viz. Case I, Case II, and Case III.

See and compare Fig. 7, 8, and 9 with Fig. 2, 3, and 4 respectively.

Note

It can be proved that the observed effects exist in a wide range of values β_y and k_m .

3. Conclusions.

After comparing the experimental and*computed data, the mathematical model seems to be fairly good.

The influence of the carriage speed on the transferfunction may be decreased by adding mass to the carriage, adjusting backlash between carriage and frame, or using a lubricate with a high viscosity.

We have to notice that the system is nonlinear. Therefore the dynamic behaviour will depend on the amplitude of the exciting force.

Using the test rig characteristics for computing the stability limit-values we must keep in mind either this nonlinearity as the velocity influence.

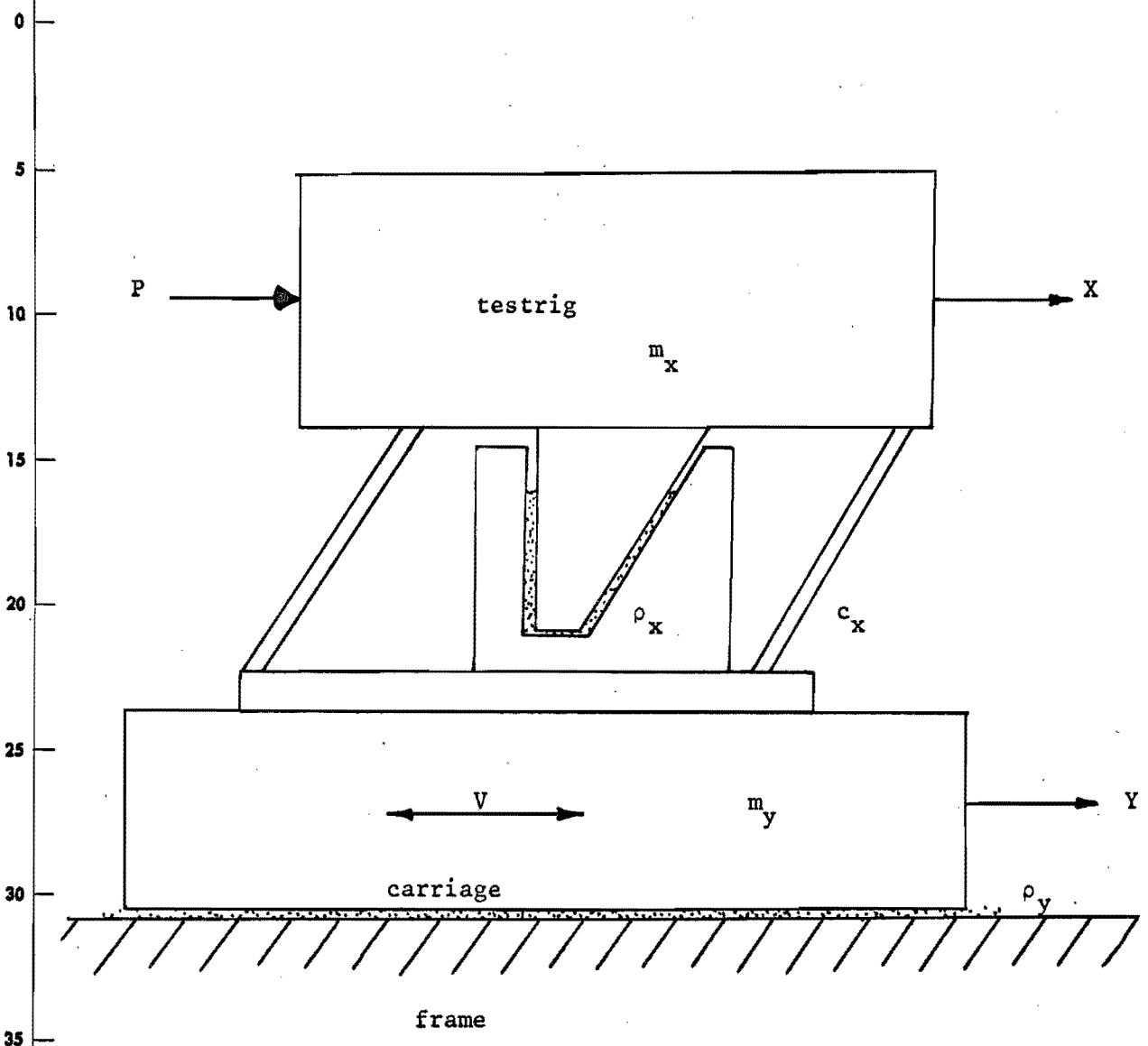


Fig. 1. Testrig mounted on the carriage.

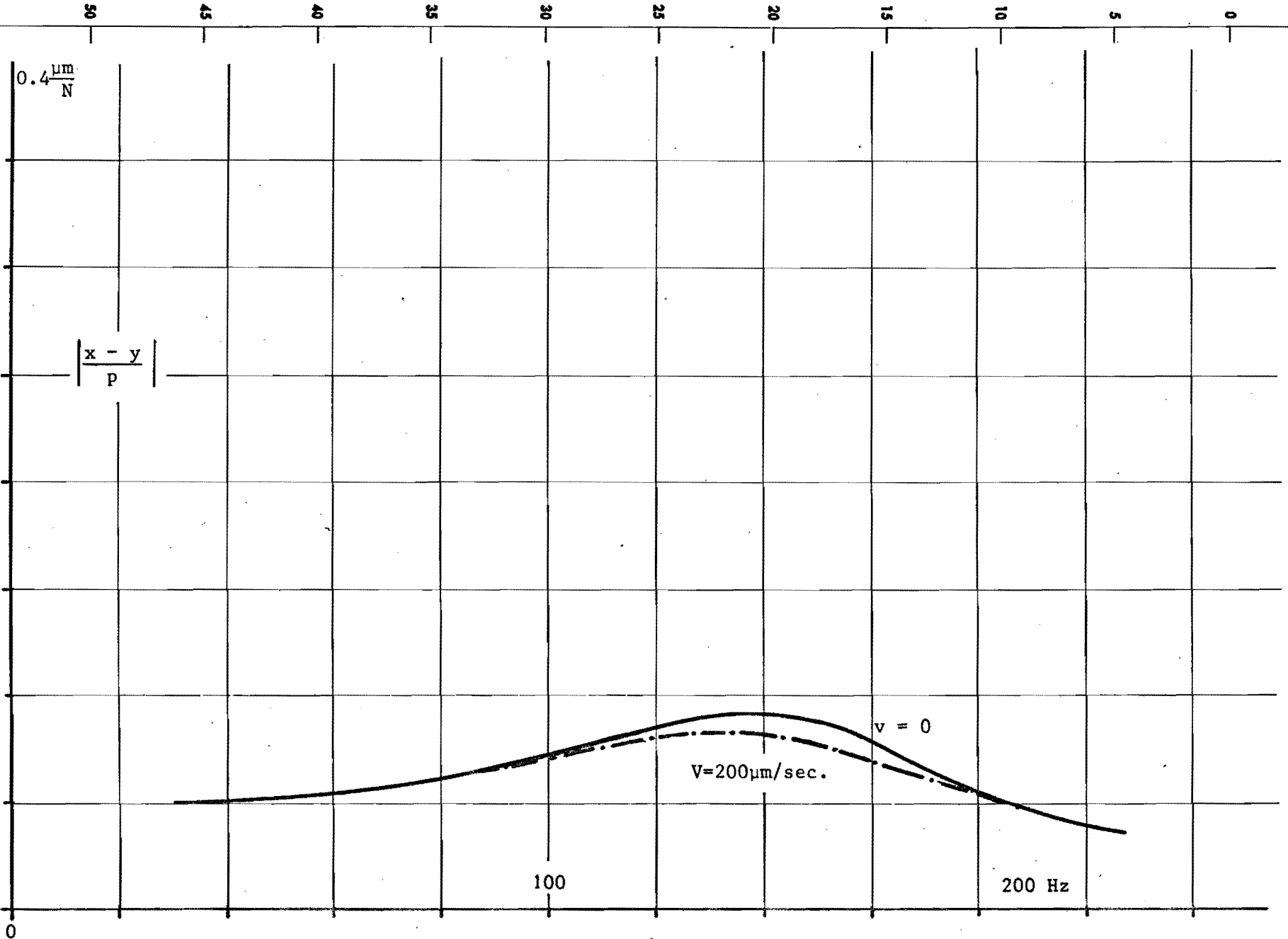
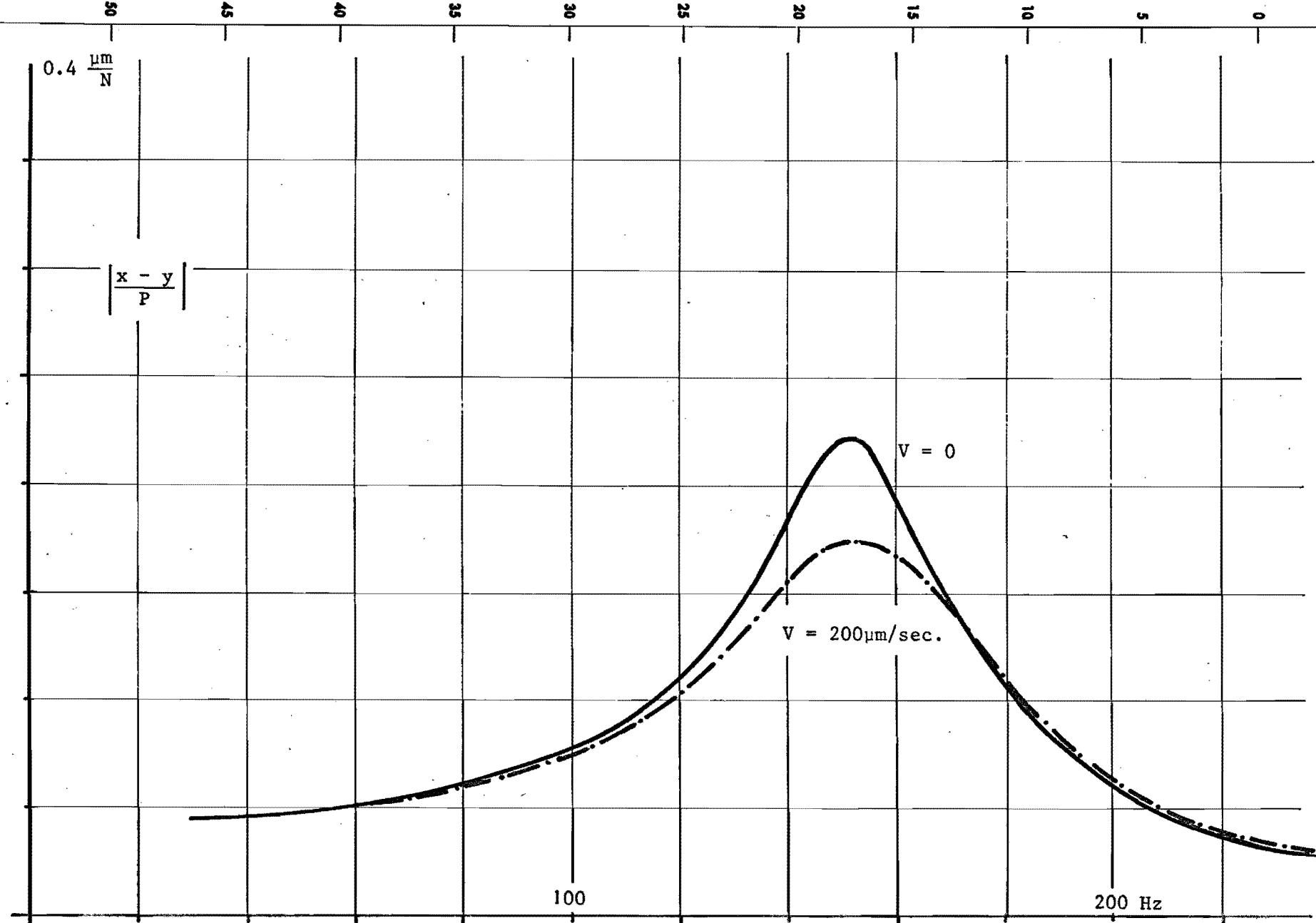


Fig. 2. Transfer function, case I.



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Fig.3. Transferfunction, case II.

0

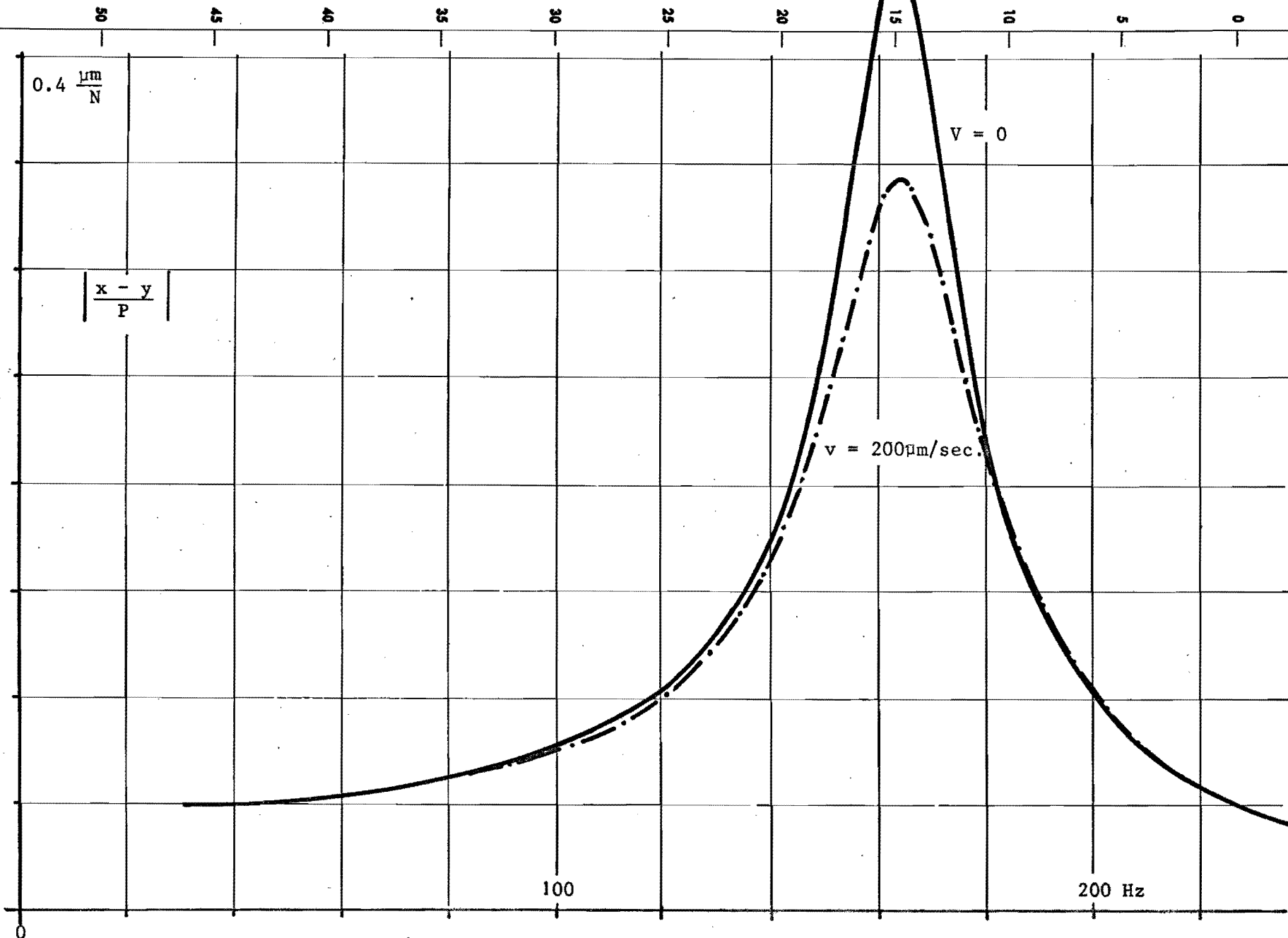


Fig. 4. Transferfunction, case III.

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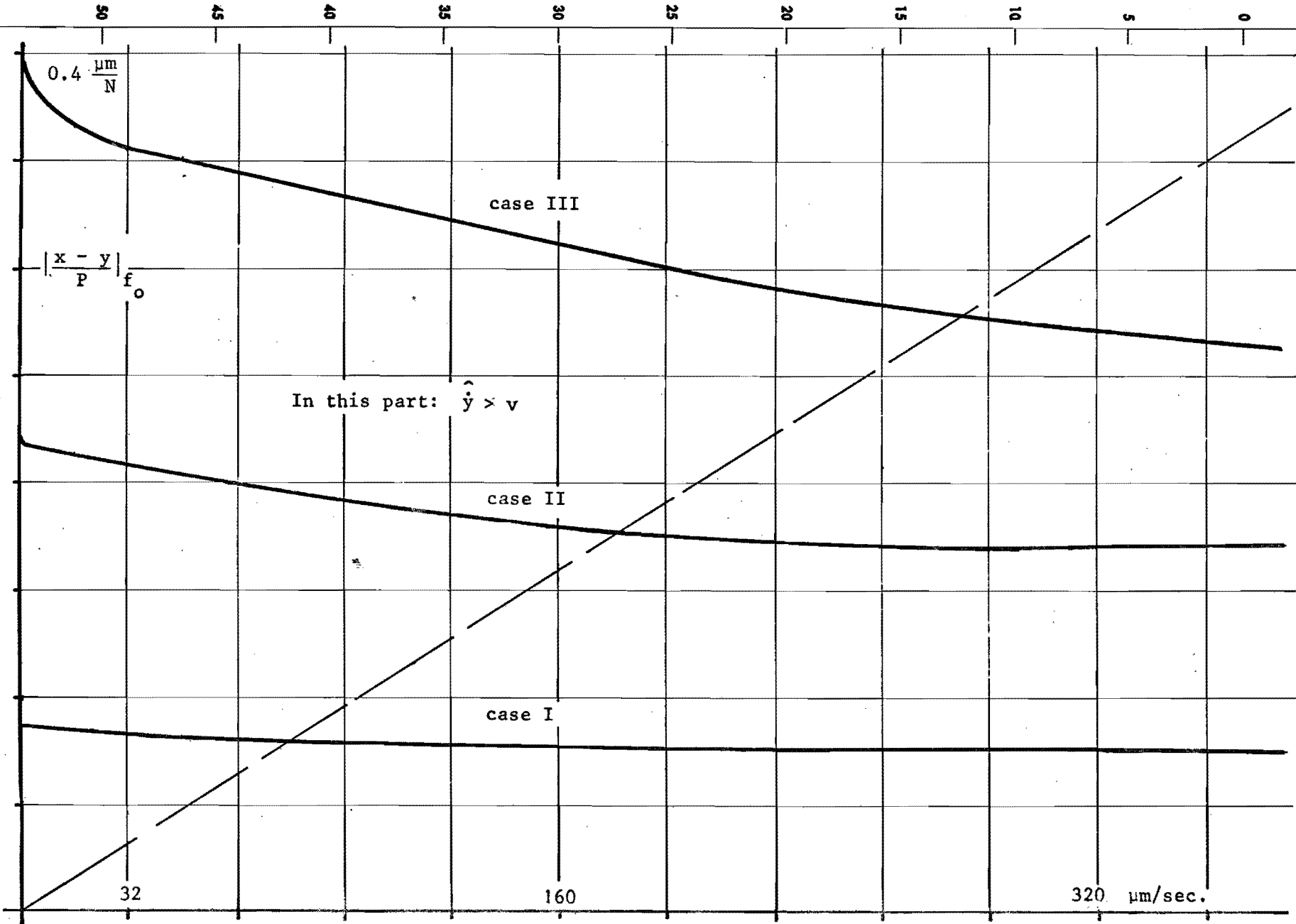


Fig. 5. Amplitude ratio $\left| \frac{x-y}{p} \right|$ at the natural frequency versus carriage-speed.

0
5
10
15
20
25
30
35
40
45
50

case I	
The signals are too small for accurate measurements.	

case II		
	$V = 0$	$V = 200 \mu\text{m}/\text{sec.}$
x	45 mV	36 mV
y	1,5 mV	3,2 mV

case III		
	$V = 0$	$V = 200 \mu\text{m}/\text{sec.}$
x	90 mV	66 mV
y	2,2 mV	3,7 mV

$$l \quad y \cong 44 \mu\text{m}$$

Table 1. Experiment data.

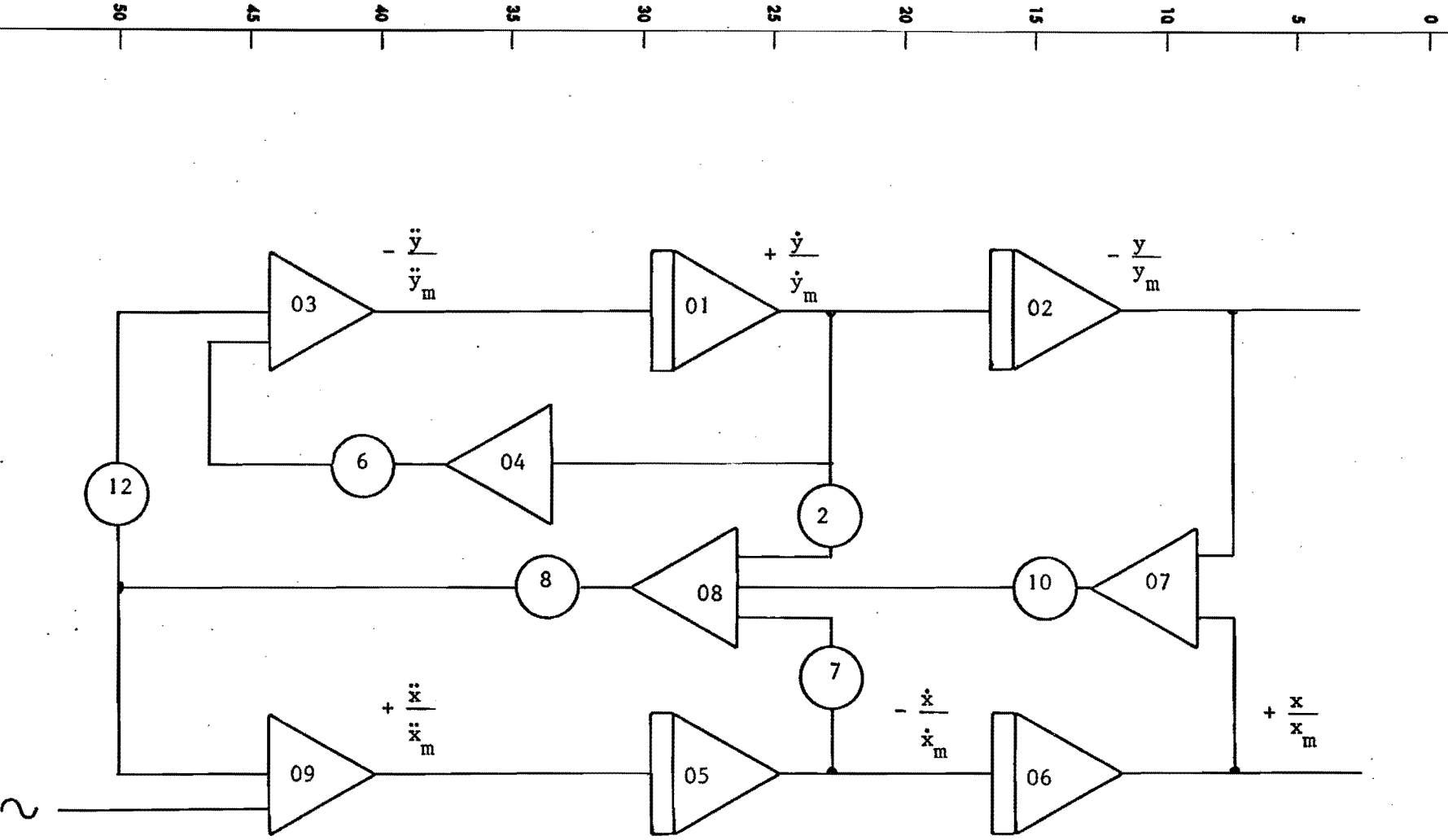


Fig.6. Analogue computer circuit.

Potentiometers

2	$2\beta_x$	8	$\frac{\omega_x}{\omega_{max}}$
6	$\frac{2\beta_y \omega_x k_m}{\omega_{max}}$	10	$\frac{\omega_x}{\omega_{max}}$
7	$2\beta_x$	12	k_m

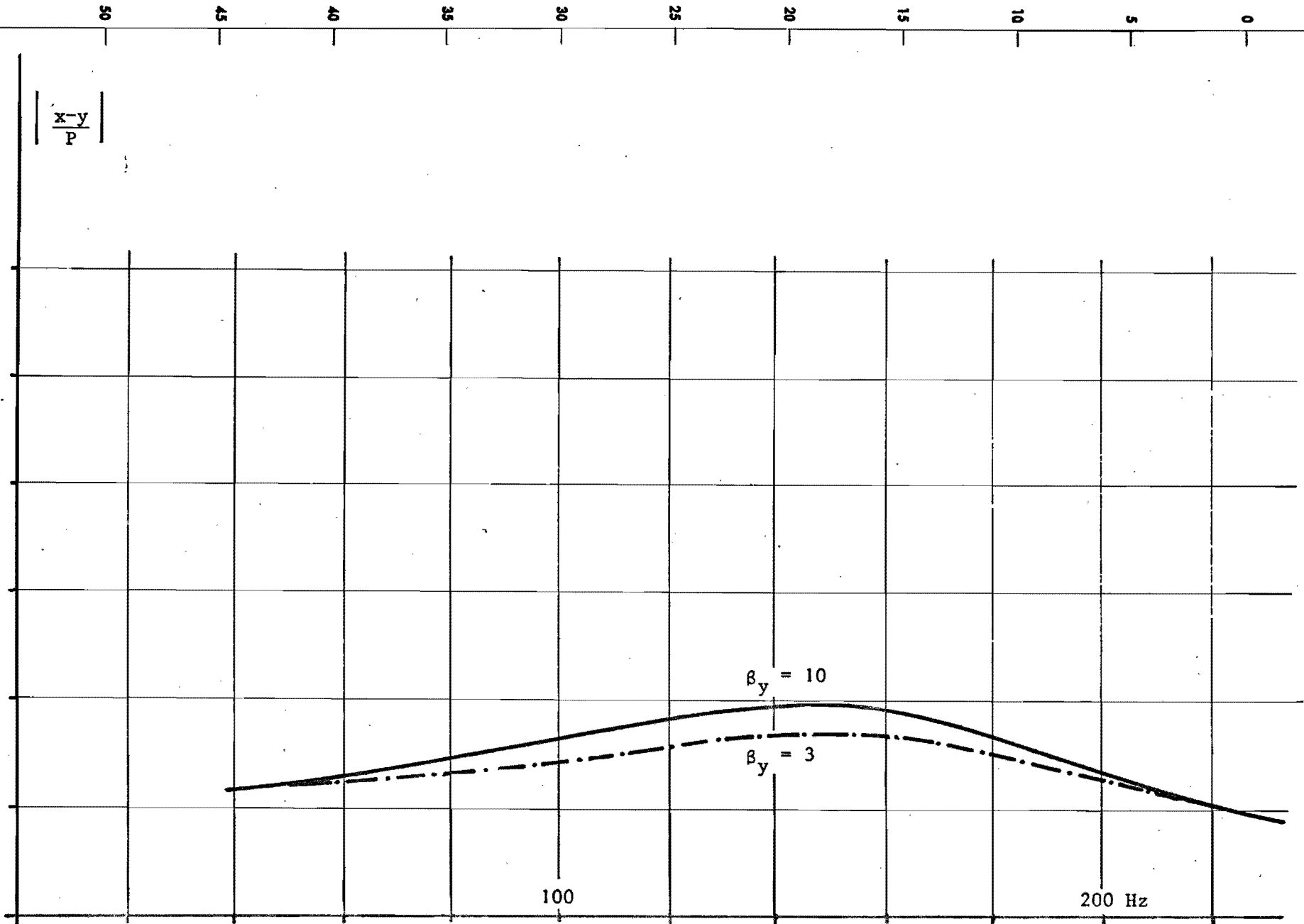


Fig. 7. Analogue computer transferfunction, case I.

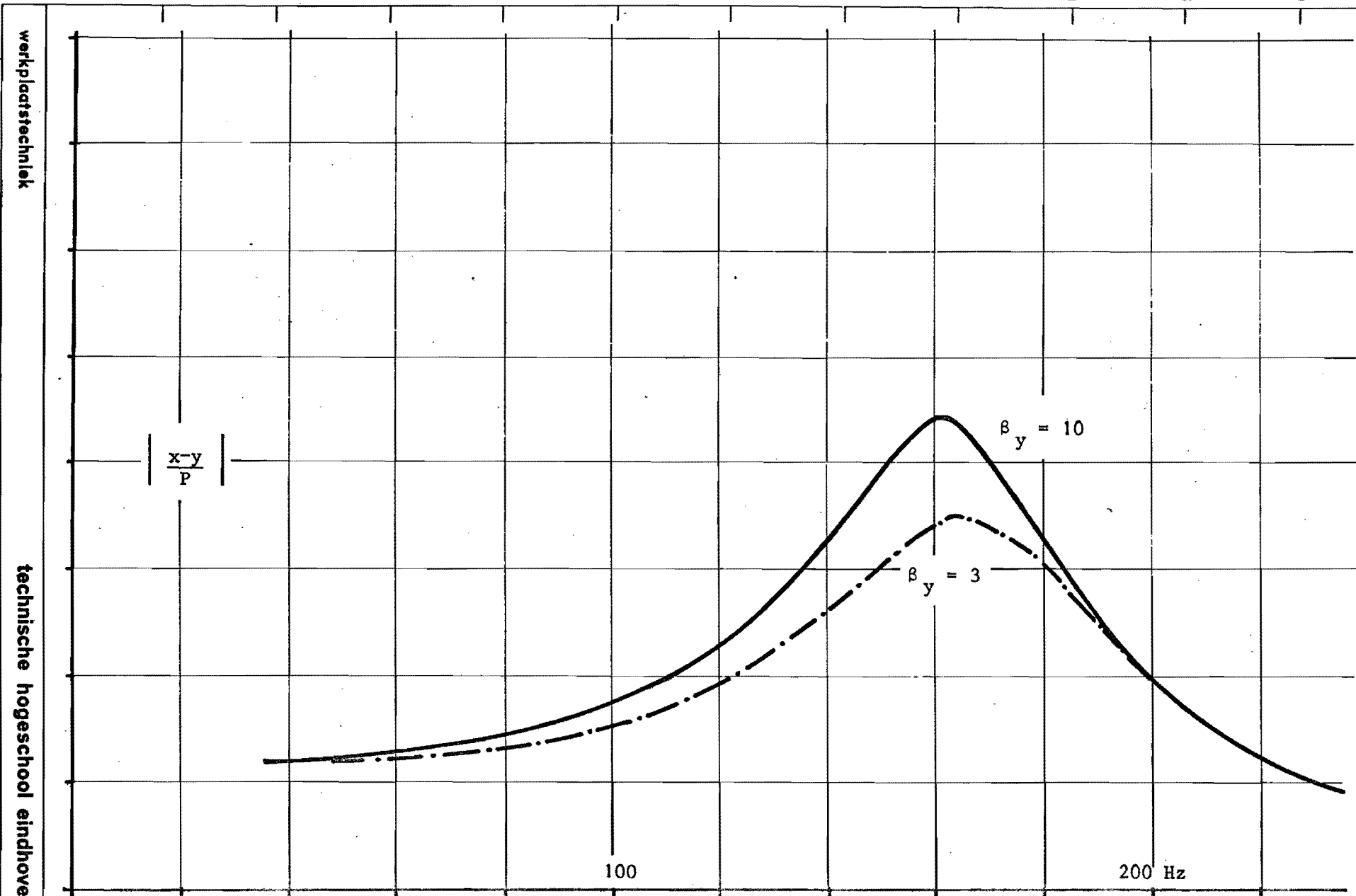


Fig. 8. Analogue computer transferfunction, case II.

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0

50

45

40

35

30

25

20

15

10

5

0

100

200 Hz

$$\frac{x-y}{P}$$

$\beta_y = 10$

$\beta_y = 3$

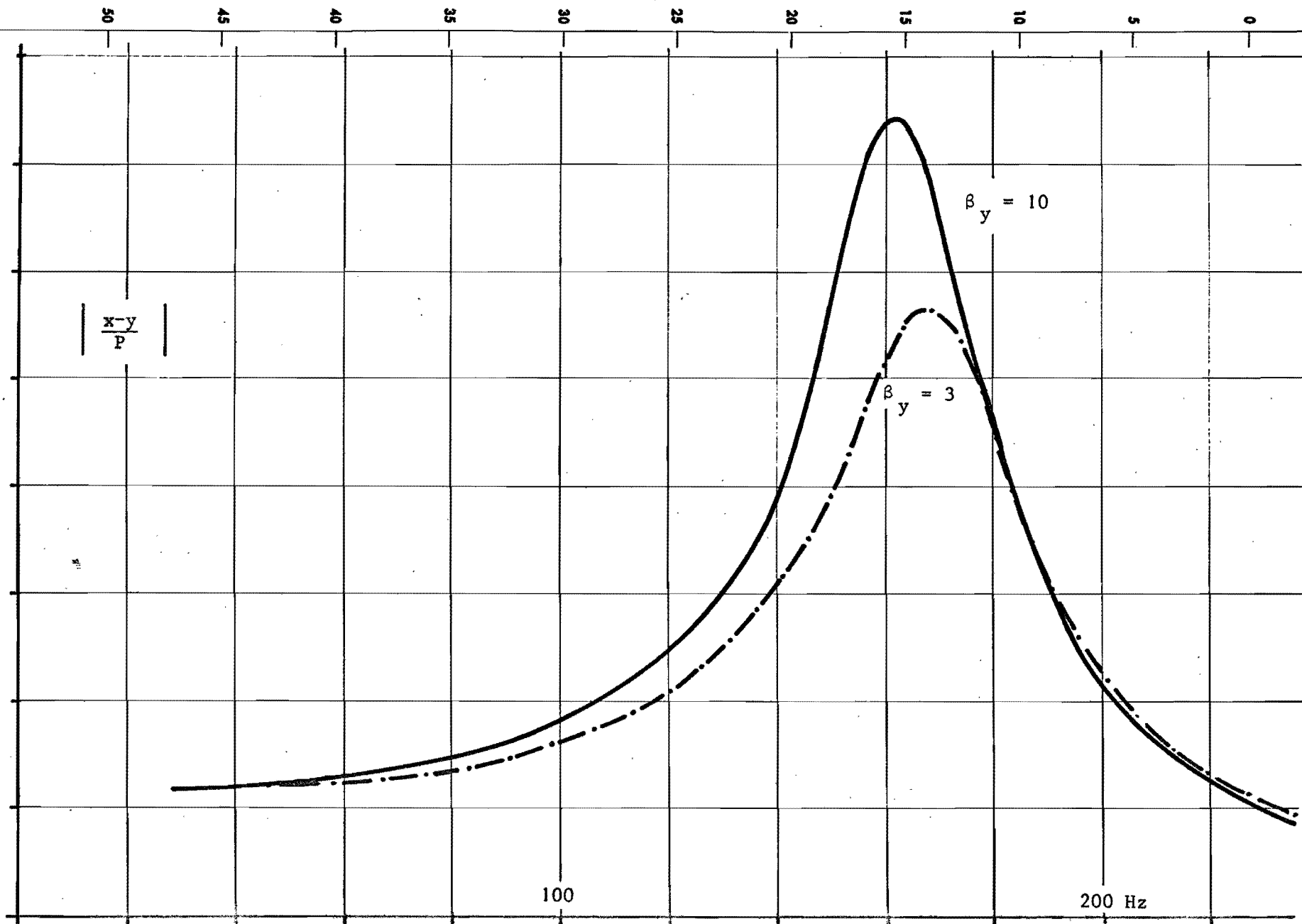


Fig. 9. Analogue computer transferfunction, case III.