Vibrations of an industrial camera

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TECHNICAL NOTE

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SUBJECT VIBRATIONS OF AN INDUSTRIAL CAMERA

In the photographic section of the Northern Electric Company's Research and Development Laboratory, the production of extremely accurate micro images is of prime importance. The ultimate resolution of the camera used for this work is decided by the level of background vibration experienced by the camera system itself. Vibration measurements were carried out to obtain the relative motion of the component parts.

GENERAL

The factors that affect the reproduction of an image when vibration is involved may be considered with reference to Figure 1. If no relative motion is involved between the camera and the object, a clear image with sharp edges and no distortion would be obtained. If, however, relative motion is involved between the camera and object in the three directions then out of focus, blurring due to longitudinal displacements, blurring due to lateral displacements, and distortion due to angular displacements may be present.

As the time of exposure is very long compared with the period of the vibrations, many displacements may take place during the exposure. Thus the important quantity is the relative displacement between camera and object.

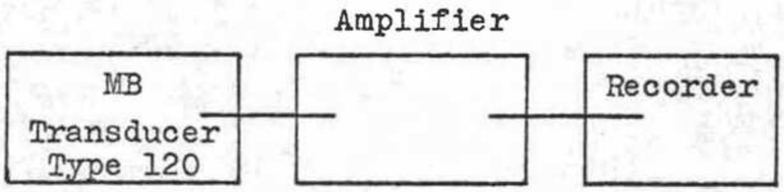
Camera Description

The photographic set-up consists of a bed with two main rails, a camera holder and an object holder. The bed is constructed basically of two parallel rails of approximately ½-in. by 3-in. steel bars several feet long and separated 2 ft apart by pieces of 3-in. steel pipe to which they are welded. The camera and object frame holder, of cast construction, are each supported on these rails by means of four rollers, two on each rail. A friction clamping mechanism secures the holders to a centre rail which runs the length of the bed and is attached to the steel pipe sections. The optical axis is about 2 ft above the rails. The whole bed is on a system of shock mounts - two at each end of the rails - to isolate the unit from external vibration.

The object holder, which is flat to take scaled drawings etc., is hinged at its middle so that it can be turned within the frame holder through 90° to face upwards for ease of operation. The clamps for this are spring-loaded tapered pegs.

MEASURING EQUIPMENT

It was desirable to measure displacement directly but equipment to do this was not available. Velocity-sensitive transducers were used with appropriate amplifiers into a galvanometer recorder. This gave a permanent record which could be examined afterwards.



This system has a flat frequency response, in terms of velocity from 5 to 700 cps.

OBSERVATIONS

The recorded vibrations are shown in records 1 to 8, and in Table I. It can be seen that generally a predominant frequency is involved and thus a fairly accurate estimate of displacement can be made.

GENERAL BACKGROUND VIBRATIONS

Longitudinal Motion

Transducers were placed on the camera face and the glass frame holder. Records 2 and 3 show that the camera and glass face move in the same direction relative to the camera bed. This indicates that the camera frame and object frame are undergoing a rocking type of motion in the longitudinal direction. The displacements are not quite the same in the two cases and would lead primarily to out-of-focus blurring and distortion due to parallax.

Transverse Motion

Transverse motion is severe on the camera and object frame (Records 1,4,5 and 6). The displacements from the optic axis are continuously varying and the relative phasing between the two is also changing. The maximum displacement for ambient background vibrations amounted to 300 micro-in. Again the motions are caused by rocking of the frame holder and perhaps racking of the camera bed, leading to severe image distortion and blurring.

Specific Sources of Vibration

The darkroom door was closed very quietly and caused considerable motion in the longitudinal direction (Record 7). A slight tap on the frame holder itself also led to large displacements (Record 8). It is presumed that similar displacements would also occur in the transverse direction, though these were not measured.

REMARKS

Both the longitudinal and transverse components of motion are severe, particularly if there is activity nearby. It is understood that the measurements were taken on what was a quiet day, since not much of the equipment was operating in the machine shops. Accordingly it is probable that vibration from the shops on busier days could lead to much larger percentage errors in the final image.

The construction of the camera system unfortunately lends itself to excitation. The camera holder and object holder are simply sitting on the rails and poorly clamped by a friction clamp. The centres of gravity of the holders are high compared with the separation of its rollers on the rails and also to the width of the rails. This high unsupported structure with virtually no positive clamping device lends itself to instability and rocking motions both longitudinally and transversely. The optical axis, high above the rails, is in such a plane that it suffers severe displacements. The damping device used for the rotating object holder was inadequate, with considerable backlash. The rails themselves rely on the weld to the steel pipes for their rigidity.

ERROR CONSIDERATIONS

Considering some of the errors involved, it appears that the best definition of a line that can be obtained by a coordinatograph is to an accuracy of $\pm$ 0.001 in. The problem is to obtain an image 0.002 in. in width to a final accuracy of $\pm \frac{1}{4}$ micron, i.e., 10 micro-in. This is equivalent to a final error of

$$\frac{0.00001 \times 100}{0.002} \text{ per cent} = 0.5 \text{ per cent}$$

Assume that the error allowed in the original art master will be 0.45 per cent to allow a little for movement of the camera. As the error in the cutting of the art master is $\pm$ 0.001 in., then the minimum width of the original object is required to be $\frac{0.001 \times 100 \text{ in.}}{0.45} = 0.22$ in.

To reduce this would require a reduction of 100:1 which could be done in two steps of 10.

Let x in. be the relative displacement of the camera and object due to vibration. On the first reduction the image error due to x will be $\frac{100x}{0.22}$ per cent.

On second reduction the image error due to x will be $\frac{100x}{0.22}$ per cent. Error due to the coordinatograph will be 0.45 per cent. Then equating the average of these errors to 0.5 per cent we arrive at

$$\sqrt{(0.45)^2 + (455x)^2 + (4550x)^2} = 0.5$$

$$x = 0.000048 \text{ in.}$$

i.e., maximum relative displacement of about 50 micro-in. To achieve this the vibration amplitudes must be reduced by a factor of about six.

Recommendations

Drastic modifications to the camera arrangement will have to be undertaken if accuracies of less than 0.5 per cent are to be obtained. It would be desirable to start off with a solid base to which the rails could be rigidly attached. A block of concrete would be ideal. The rails themselves would be on the style of a lathe bed, but possibly further apart. The holders for the camera and slides could be mounted on lathe-type slides with positive locks on each rail. It would be advisable to have the block supported by a low frequency shock mount to isolate it from external vibration. The whole system depends on how well the camera and object holders are attached to the rails. This is where the present system fails seriously. Such a system would then keep the relative motion between camera and object to a reasonable minimum, and should achieve the desired result.

TABLE I

VIBRATION MEASUREMENTS

Vibration Source	Measuring Position	Vertical Component			Longitudinal Component			Transverse Component		
		Measured		Computed	Measured		Computed	Measured		Computed
		Maximum Velocity in./sec x 10^{-3}	Frequency, cps	Displacement, micro-in.	Maximum Velocity, in./sec x 10^{-3}	Frequency, cps	Displacement, micro-in.	Maximum Velocity, in./sec x 10^{-3}	Frequency, cps	Displacement, micro-in.
General background vibrations	Centre of camera bed	4.8	30	26	1.0	50	3			
	Frame holder				4.8	20	40	12.0	6.7	300
	Frame holder				2.4	6.2	65			
	Glass frame				7.7	6.3	170			
	Camera face				9.1	6.2	205	7.9	5.0	280
	Floor	6.0	22	45	0.5	30	3	1.9	21	14
Dark-room door closed very quietly	Centre of camera bed				4.8	25	30			
	Frame holder				26.4	25	160			
	Glass frame				43.2	25	270			
	Camera face				45.6	25	290			
Slight tap on frame holder	Centre of camera bed	9.6	80	20						
	Frame holder				40.8	60	110			
	Glass frame				48.0	60	120			
	Camera face				1.9	60	5			
	Camera face				7.2	6.2	185			

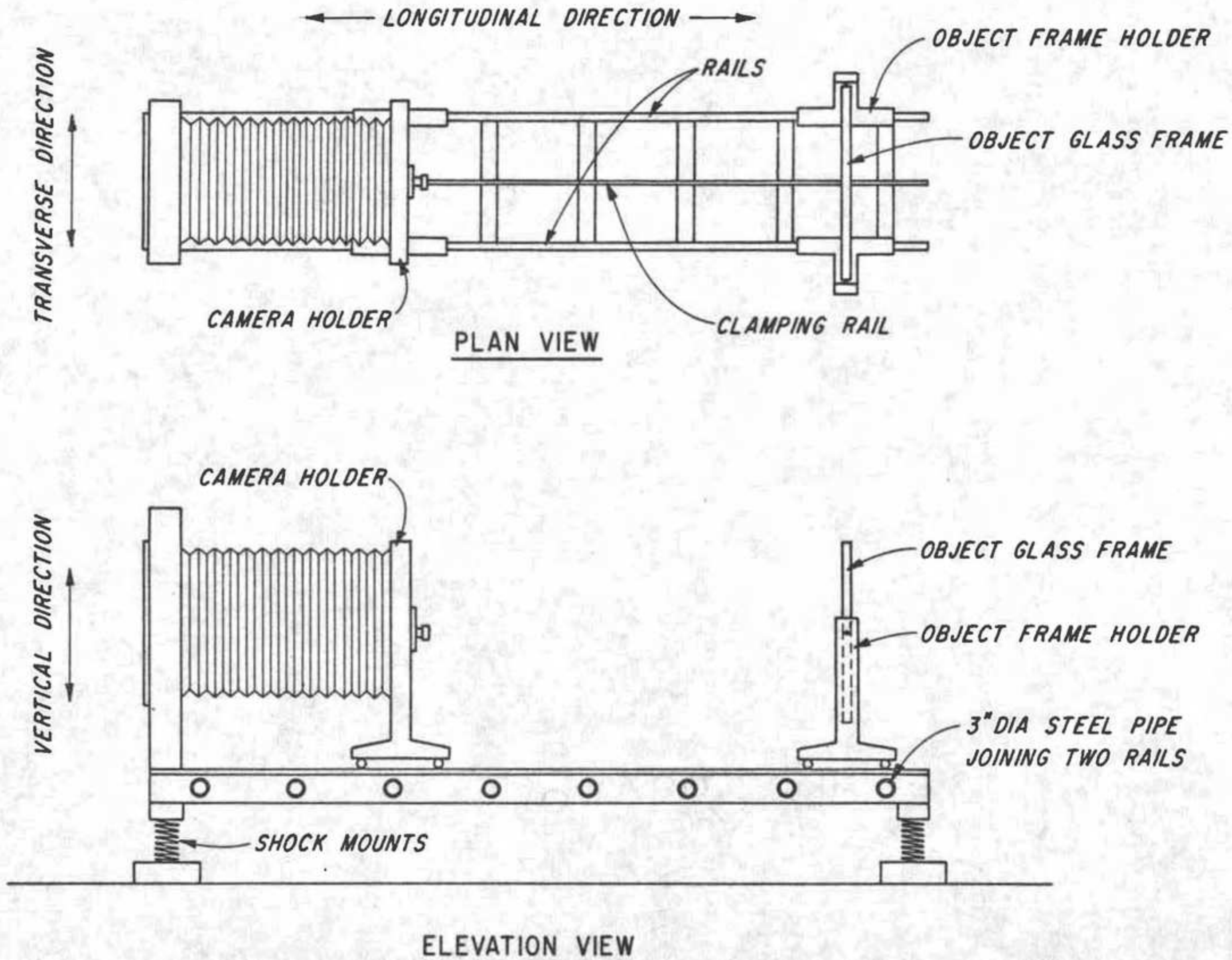
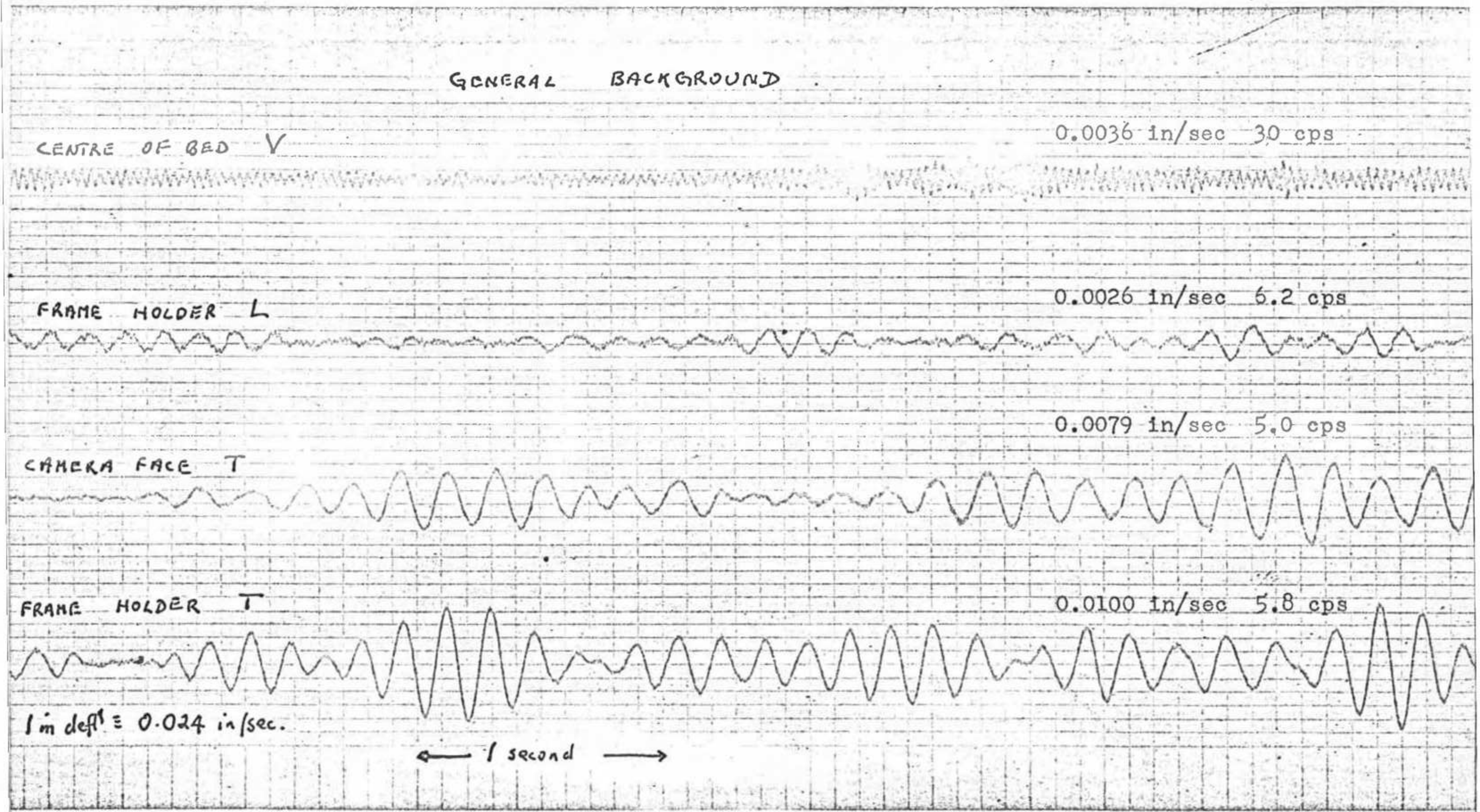


FIGURE 1

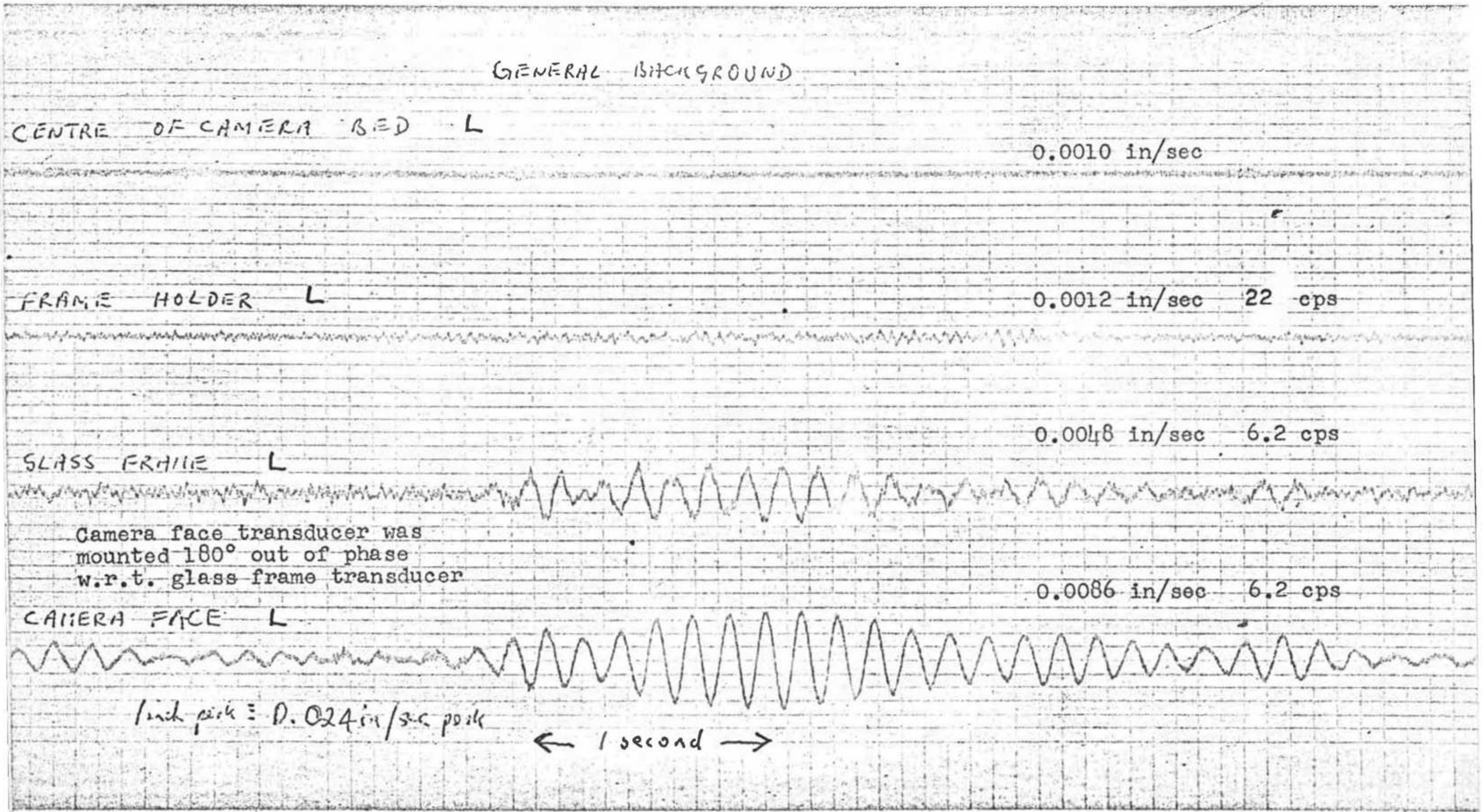
SCHEMATIC LAYOUT OF CAMERA SET-UP AT NORTHERN ELECTRIC COMPANY, OTTAWA

BR. 3006

Record 1

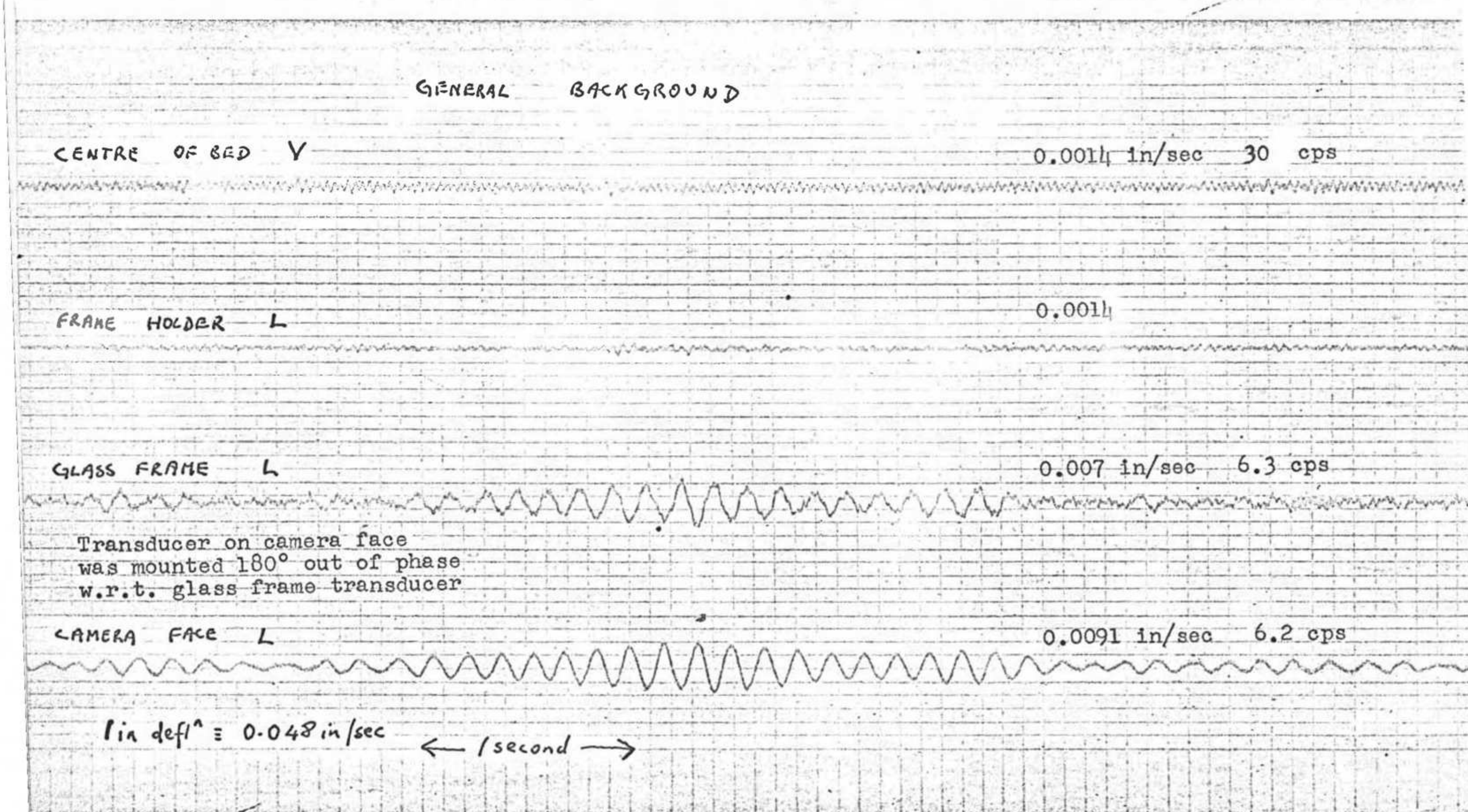

GENERAL BACKGROUND
CENTRE OF BED V
0.0036 in/sec 30 cps
FRAME HOLDER L
0.0026 in/sec 6.2 cps
CAMERA FACE T
0.0079 in/sec 5.0 cps
FRAME HOLDER T
0.0100 in/sec 5.8 cps
1 in defl = 0.024 in/sec.
← 1 second →

Record 2



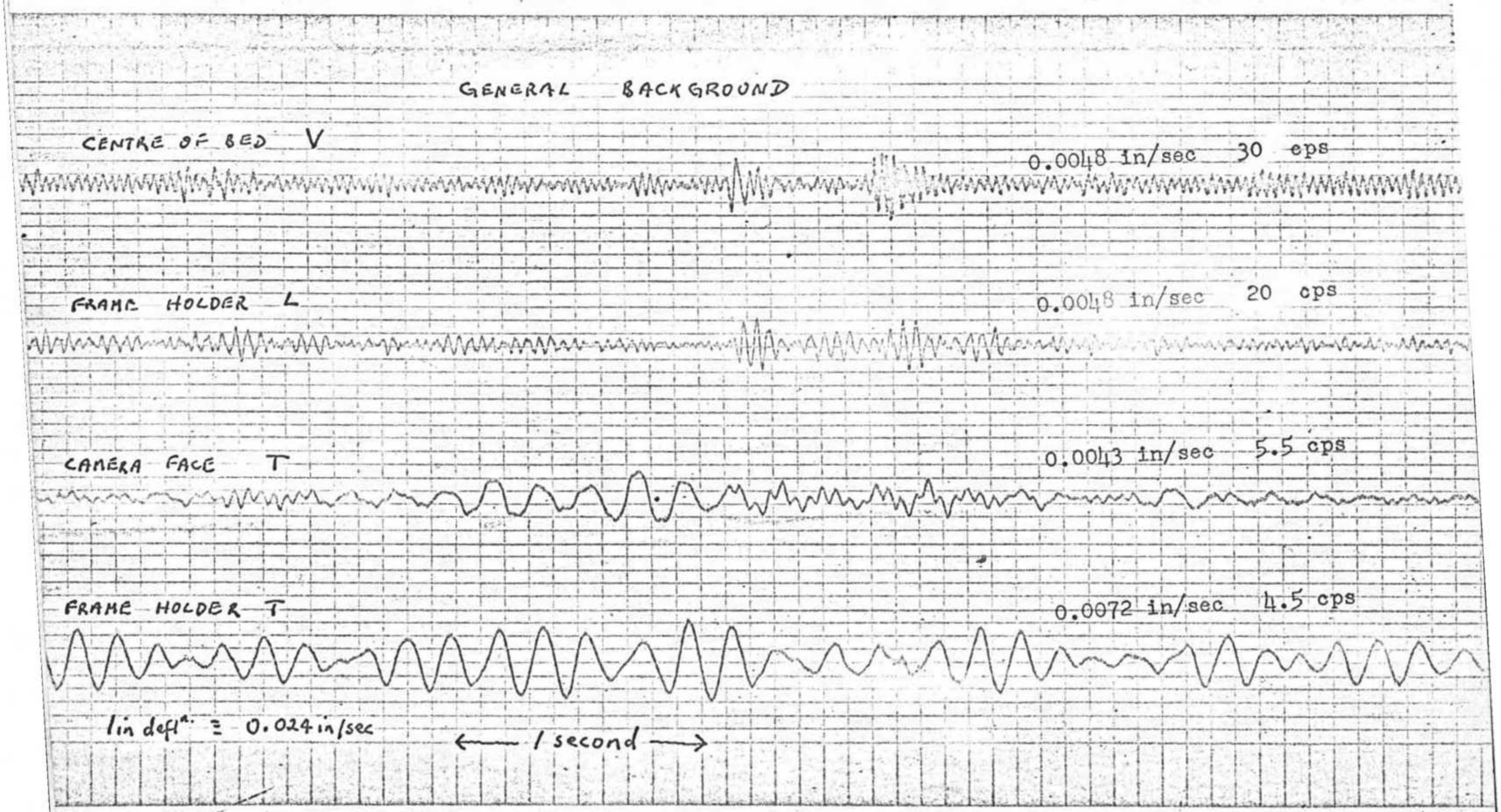
GENERAL BACKGROUND
CENTRE OF CAMERA BED L
0.0010 in/sec
FRAME HOLDER L
0.0012 in/sec 22 cps
0.0048 in/sec 6.2 cps
GLASS FRAME L
Camera face transducer was mounted 180° out of phase w.r.t. glass frame transducer
0.0086 in/sec 6.2 cps
CAMERA FACE L
1 inch peak = 0.024 in/sec peak
← 1 second →

Record 3

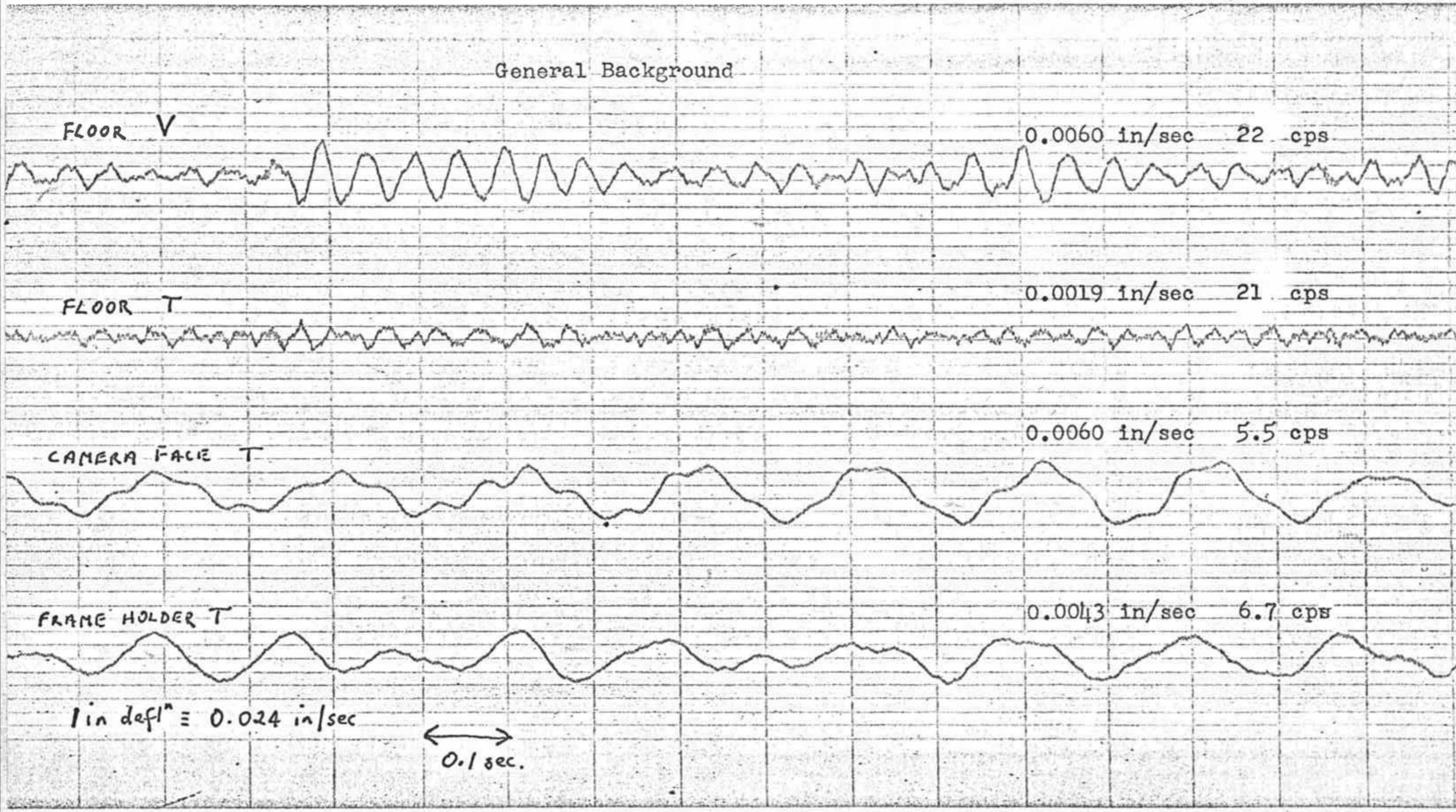


GENERAL BACKGROUND
CENTRE OF BED V
0.0014 in/sec 30 cps
FRAME HOLDER L
0.0014
GLASS FRAME L
0.007 in/sec 6.3 cps
Transducer on camera face
was mounted 180° out of phase
w.r.t. glass frame transducer
CAMERA FACE L
0.0091 in/sec 6.2 cps
1 in defl^n ≡ 0.048 in/sec
← 1 second →

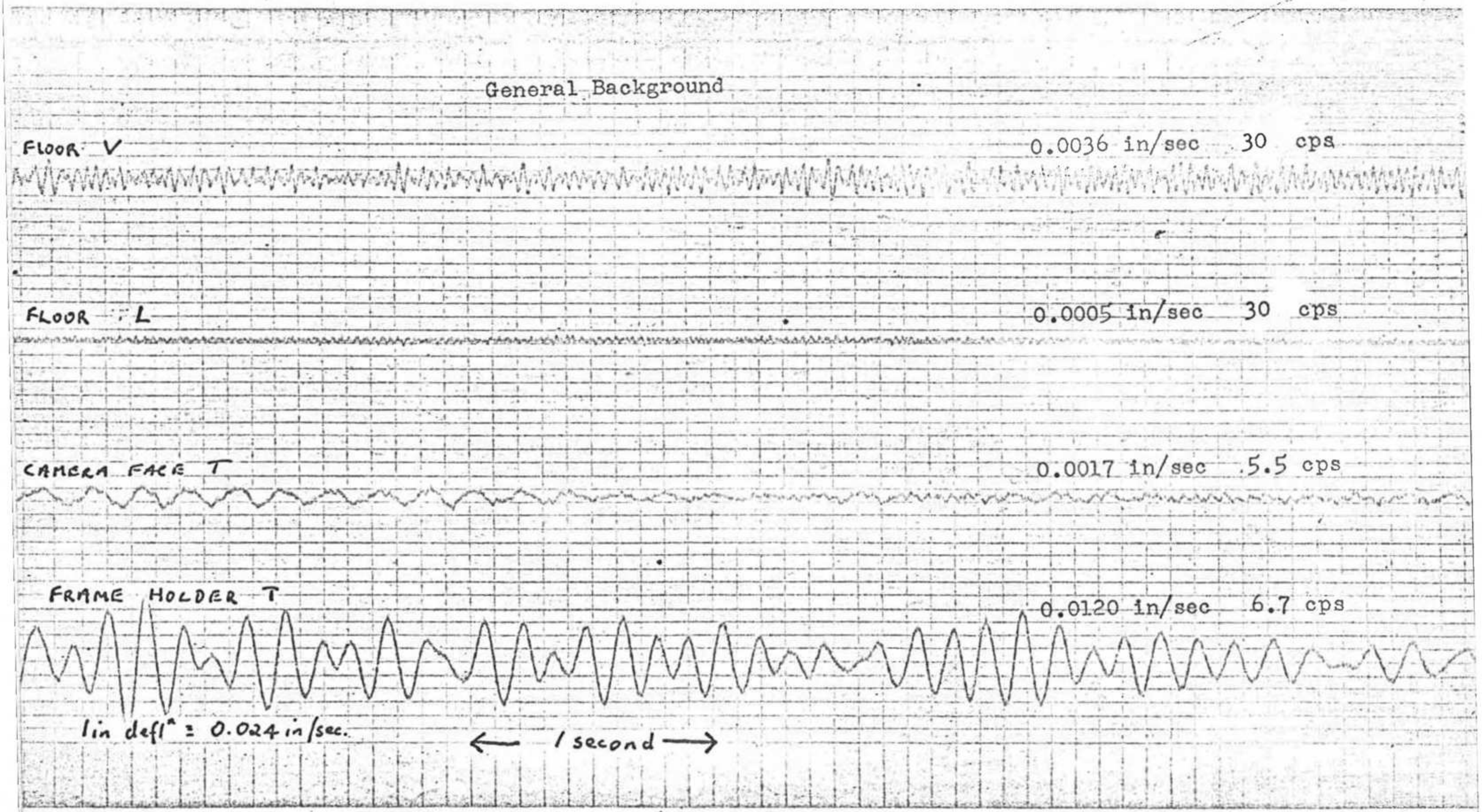
Record 4


GENERAL BACKGROUND
CENTRE OF BED V
0.0048 in/sec 30 cps
FRAME HOLDER L
0.0048 in/sec 20 cps
CAMERA FACE T
0.0043 in/sec 5.5 cps
FRAME HOLDER T
0.0072 in/sec 4.5 cps
1in defl^n. ≡ 0.024 in/sec
← 1 second →

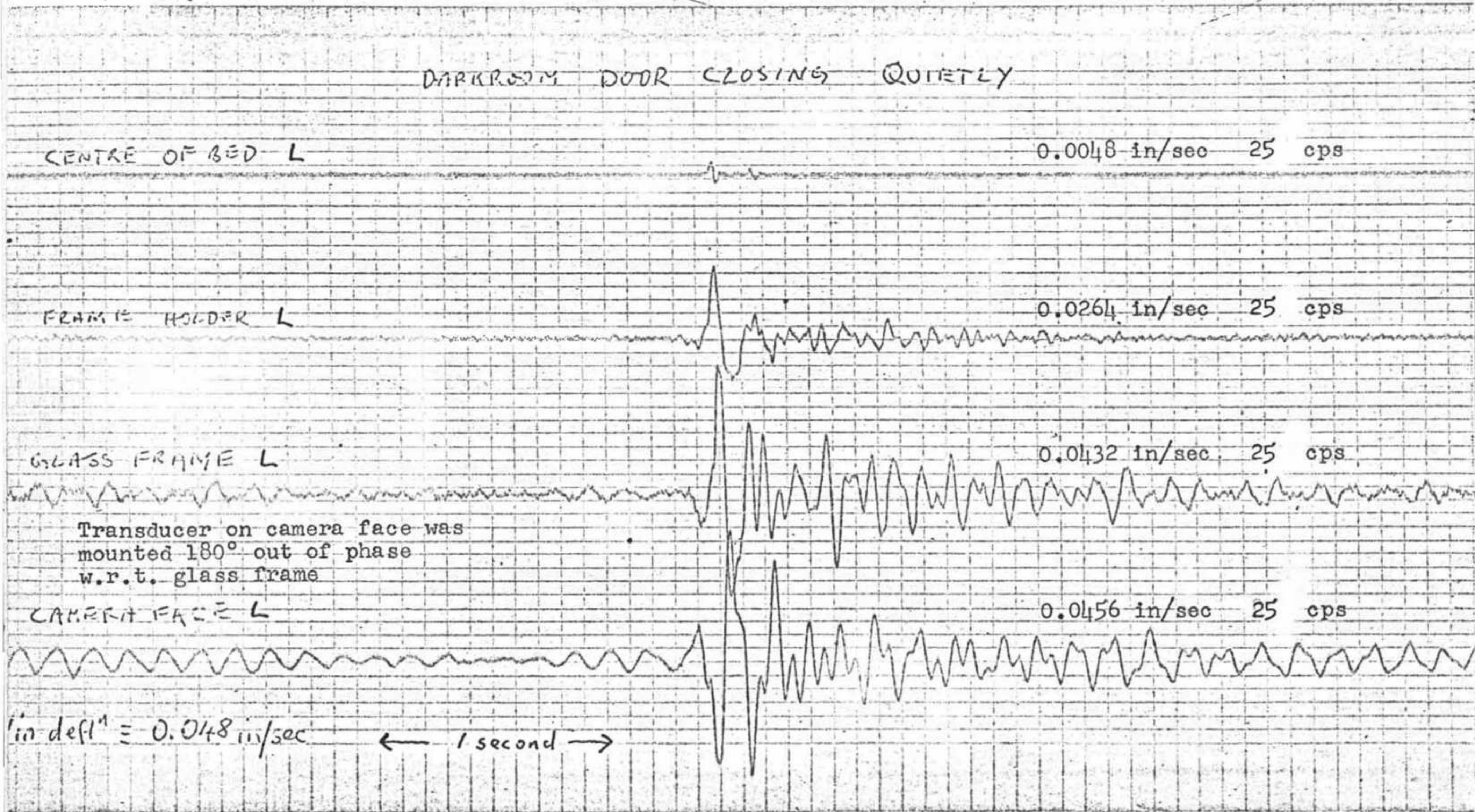
Record 5


General Background
FLOOR V
0.0060 in/sec 22 cps
FLOOR T
0.0019 in/sec 21 cps
CAMERA FACE T
0.0060 in/sec 5.5 cps
FRAME HOLDER T
0.0043 in/sec 6.7 cps
1 in defl" ≡ 0.024 in/sec
0.1 sec.

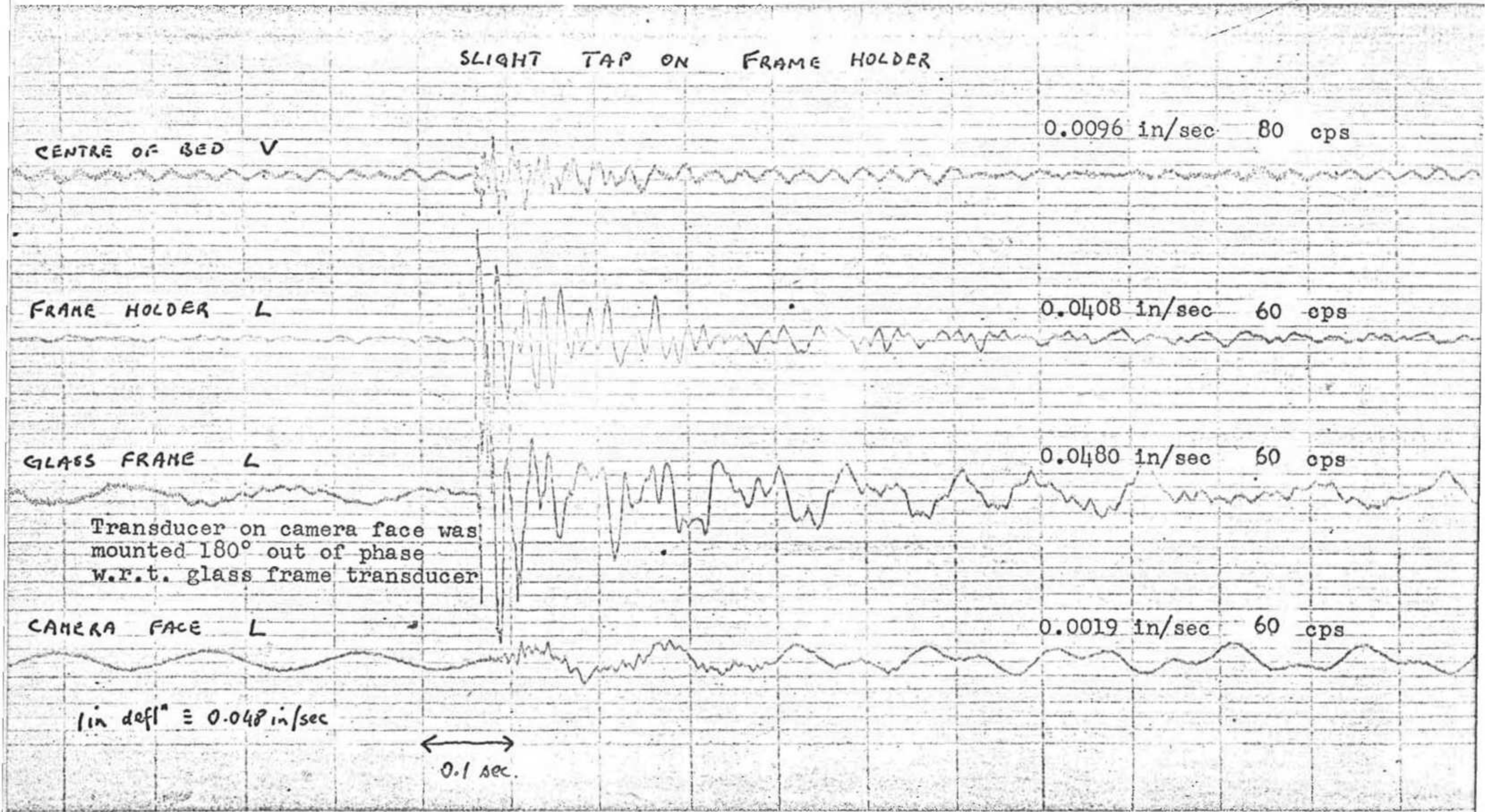
Record 6


General Background
FLOOR V
0.0036 in/sec 30 cps
FLOOR : L
0.0005 in/sec 30 cps
CAMERA FACE T
0.0017 in/sec 5.5 cps
FRAME HOLDER T
0.0120 in/sec 6.7 cps
1 in defl^n = 0.024 in/sec.
← 1 second →

Record 7


DARKROOM DOOR CLOSING QUIETLY
CENTRE OF BED L
0.0048 in/sec 25 cps
FRAME HOLDER L
0.0264 in/sec 25 cps
GLASS FRAME L
0.0432 in/sec 25 cps
Transducer on camera face was mounted 180° out of phase w.r.t. glass frame
CAMERA FACE L
0.0456 in/sec 25 cps
1 in defl^n ≡ 0.048 in/sec
← 1 second →

Record 8



SLIGHT TAP ON FRAME HOLDER
CENTRE OF BED V
0.0096 in/sec 80 cps
FRAME HOLDER L
0.0408 in/sec 60 cps
GLASS FRAME L
0.0480 in/sec 60 cps
Transducer on camera face was mounted 180° out of phase w.r.t. glass frame transducer
CAMERA FACE L
0.0019 in/sec 60 cps
1in defl^{n} ≡ 0.048 in/sec
0.1 sec.