SSC-N-198

# JOSTLE: A BEAM CENTERING STUDY FOR SSC

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## JOSTLE

An interactive program, JOSTLE, has been developed to test the Jostlein[1] method of beam collision centering for the SSC. In this method a small sinusoidal steering signal causes each beam to circle about its nominal direction. If the nominal directions coincide at beam crossing, their transverse separation is fixed at the circle diameter. If the nominal beam directions are offset, the counting rate for secondary particles from the pp interactions varies with the phase of the circular steering. This counting-rate response can be used to determine a feedback steering correction to bring the beams into direct collision.

JOSTLE is designed to provide the user with interactive control of the various simulated beam errors and of the sampling and steering parameters so that studies of beam tracking and luminosity degradation can be made for a variety of potential conditions.

## SIGNAL

The expected number of secondaries from 50,000 ISAJET generated minimum bias events is plotted as a function of angle in Figure 1. When translated to particle flux at 20 meters, we find (counting pi-zeroes)

at 1 milliradian ( 2 cm from beam line), 0.2 /$cm^2$/event;

at 2 milliradians ( 4 cm from beam line), 0.05;

at 4 milliradians ( 8 cm from beam line), 0.015;

at 8 milliradians (16 cm from beam line), 0.004.

At design luminosity there are 100,000,000 events per second producing 1,000,000 to 250,000 counts per second in a five-square-millimeter counter placed 2 to 4 cm from the beam line at a distance of 20 meters from the interaction point. The flood of secondary particles makes this scheme not only viable, but one with fast response so that tracking a transverse movement of many microns per second or following coherent steering-magnet noise with frequencies up to several Hertz is straight forward without serious luminosity loss.

## PARAMETERS

The transverse beam distribution is taken to be a gaussian with standard deviation $s_x$ in the x projection and a gaussian with standard deviation $s_y$ in the y projection. Both beams have the same parameter values. If the beams are separated by transverse distances $a_x$ and $a_y$ in the x and y directions, then the number of secondary counts in time $T$ is

$$N = RT\left(\frac{s_{x0}s_{y0}}{s_x s_y}\right)\exp\left(-\frac{a_x^2}{4s_x^2}\right)\exp\left(-\frac{a_y^2}{4s_y^2}\right)$$

where $R$ is the counting rate for no separation ($a_x = a_y = 0$) at the design beam size $s_{x0}$ and $s_{y0}$.

We suppose the beam separation to be given by

$$a_x = b_x + d_x, \qquad \text{and} \qquad a_y = b_y + d_y$$

where $b_x$ and $b_y$ are harmonically driven amplitudes with $90^o$ phase difference for use in Jostlein tuning and $d_x$ and $d_y$ are caused by steering errors:

$$b_x = b_{x0}cos(2\pi f_{bx}t),$$

$$b_y = b_{y0}sin(2\pi f_{by}t);$$

$$d_x = d_{x0} + d_{x1}sin(2\pi f_{cx}t + \phi_{cx}) + d_{x2}.$$

$$d_y = d_{y0} + d_{y1}sin(2\pi f_{cy}t + \phi_{cy}) + d_{y2}.$$

$d_{x0}$ and $d_{y0}$ are stationary error offsets, $d_{x1}$ and $d_{y1}$ are amplitudes for coherent-oscillation errors with frequencies $f_{cx}$ and $f_{cy}$ and phases $\phi_{cx}$ and $\phi_{cy}$. $d_{x2}$ and $d_{y2}$ are random error displacements having gaussian distributions with standard deviations $s_{rx}$ and $s_{ry}$.

The JOSTLE user has access to all parameters except that $s_{x0} = 7$ microns and $s_{y0} = 7$ microns are imposed. The default values of the other parameters are:

$R = 100000$ per second, $T = 1$ second

$s_x = s_y = 7$ microns.

$b_{x0} = b_{y0} = 1$ micron, $f_{bx} = f_{by} = 1000$ Hz.

$d_{x0} = d_{y0} = d_{x1} = d_{y1} = 0$ microns.

$f_{cx} = f_{cy} = 0$ Hz. $\phi_{cx} = \phi_{cy} = 0$ degrees.

$s_{rx} = s_{ry} = 0$ microns.

($d_{x2}$ and $d_{y2}$ are randomly generated for each event if required.)

## COUNTS

The number of counts is generated by Monte Carlo according to the following procedure. When the beams are coincident at beam crossing the next count occurs at incremental time $\delta t$ with probability proportional to $\exp(-R\delta t)$. This time is generated by Monte Carlo. The detuned rate is down by a factor

$$\left(\frac{s_{x0}s_{y0}}{s_x s_y}\right)\exp\left(-\frac{a_x^2}{4s_x^2}\right)\exp\left(-\frac{a_y^2}{4s_y^2}\right).$$

If the computed factor at the new accumulated time $t = t + \delta t$ is greater than a random number between 0 and 1, the count is incremented. The values of $cos(2\pi f_{cx}t + 2\pi\phi_{cx}/360)$, $cos(2\pi f_{cy}t + 2\pi\phi_{cy}/360)$, and their squares are accumulated. This procedure is repeated until total run time T is exceeded. The result of the run consists of $N$, $< cosx >$, $d < cosx >$, $< cosy >$, and $d < cosy >$.

## TUNING

Figure 2 shows $< cosx >$ as a function of beam separation for the default parameter values. It can be seen that $< cosx >$ is a reasonably linear measure of beam separation. An imposed beam steering shift of 200$< cosx >$ microns brings, to good approximation, the beams into direct collision and the feedback tracking procedures which are described below are based upon this beam steering shift. However, the program user has the option of setting an additional feedback amplification factor to enhance or reduce the beam steps in tracking.

## SENSITIVITY

Examples to illustrate sensitivity of the Jostlein method are illustrated in Figures 3-7. Figure 3 shows the luminosity reduction factor as a function of the applied beam circle-driver amplitude. Note that the loss of luminosity is negligible for a 1 micron amplitude (and 7 micron beams). Figure 4 shows the relative luminosity as a function of a coherent-noise amplitude. Figure 5 shows the steering correction obtained with 0.2 second samplings of a 100000 Hz signal rate in response to a coherent error beam displacement with 20-micron amplitude and 0.1 Hz frequency. The applied beam-circling rate has a frequency which must be a multiple of the 5 Hz sampling rate. Figure 6 shows the mean cosine of the phase angle which is used to derive the beam steering correction for each sample. The resulting relative luminosity is shown in Figure 7. The average loss of luminosity is one to two per cent. If this were a long term coherent noise source, the tracker could be trained for negligible loss even from much larger displacements.

## INVITATION

JOSTLE is an interactive program which may be entertaining for would-be beam operators to try out. Copy csa4::[stork.center]jostle.for and jostle.com to your VAX account, edit jostle.com as suitable for your directory. With @JOSTLE you too will experience a great sense of power in manipulating the 405 MJ colliding beams.

Acknowledgment: I am indebt to Don Groom for his memo to assist us writing and to Dave Bintinger for speling.

## ADDENDUM (June 30, 1986)

The above note was distributed on November 4 within the Central Design Group as an informal draft. It formed the basis for the collision assurance system described in the Conceptual Design Report. On the occasion of Snowmass, 1986, it has been resurrected with minor corrections as a formal note. The original monitoring scheme described above is both naive and crude and we now know that with electromagnetic calorimetry in the neutral interacting beam dump the statistical precision is about two orders of magnitude better than that used in the examples in this note (see SSC-N-182, Figure 4). It will be important to optimise the design of a lumiosity detector with respect to the signal to noise ratio. The choice of 1000 Hz for the beam driver frequency was somewhat arbitrary and the impact of the driven beam oscillation on normal machine performance needs investigation. Any deleterious resonance effect could be ameliorated by frequency ramping the beam driver.

If we scale the example given above to one limited by calorimeter statistics, the figures describe the response with 2 ms sampling to a 10-Hz 20-micron oscillating beam-separation error, again with 1 to 2 per cent luminosity loss. At times of maximum rate of change of separation, about 1 mm per second, the loss becomes 2 to 4 per cent.

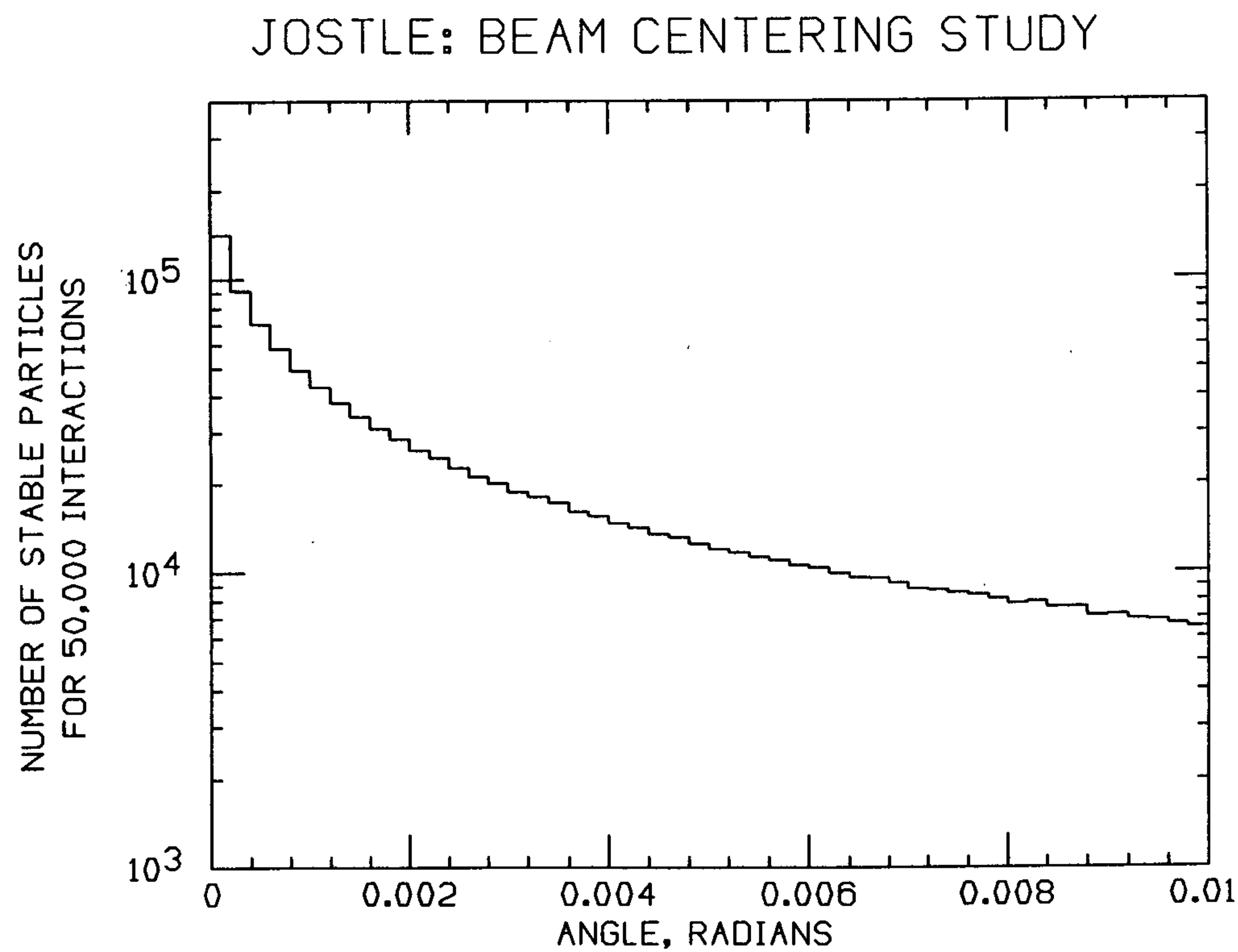
With Fourier analysis and smart feedback, more complicated oscillations can be tightly tracked. It is clear that with this feedback scheme the beams can be steered to ride through reasonable mechanical vibrations, magnet steering errors, and nondestructive earth tremors without serious loss of luminosity.

# REFERENCES


1. H. Jostlein, Fermilab Report TM-1253 (1984).


# FIGURE CAPTIONS

1. Particles from 50,000 ISAJET minimum bias events as a function of angle.
2. Luminosity as a function of beam separation.
3. Mean value of the cosine of the phase angle weighted by luminosity as a function of beam separation.
4. Luminosity as a function of the amplitude of an oscillating beam separation. Cirles, horizontal only; crosses, incoherent horizontal and vertical oscillations.
5. Displacement tracked in the illustrative example.
6. Mean cosine measured in the tracking of Figure 5.
7. Luminosity measured during the tracking of Figure 5.



JOSTLE: BEAM CENTERING STUDY
NUMBER OF STABLE PARTICLES
FOR 50,000 INTERACTIONS
10^5
10^4
10^3
0
0.002
0.004
0.006
0.008
0.01
ANGLE, RADIANS


FIGURE 1.

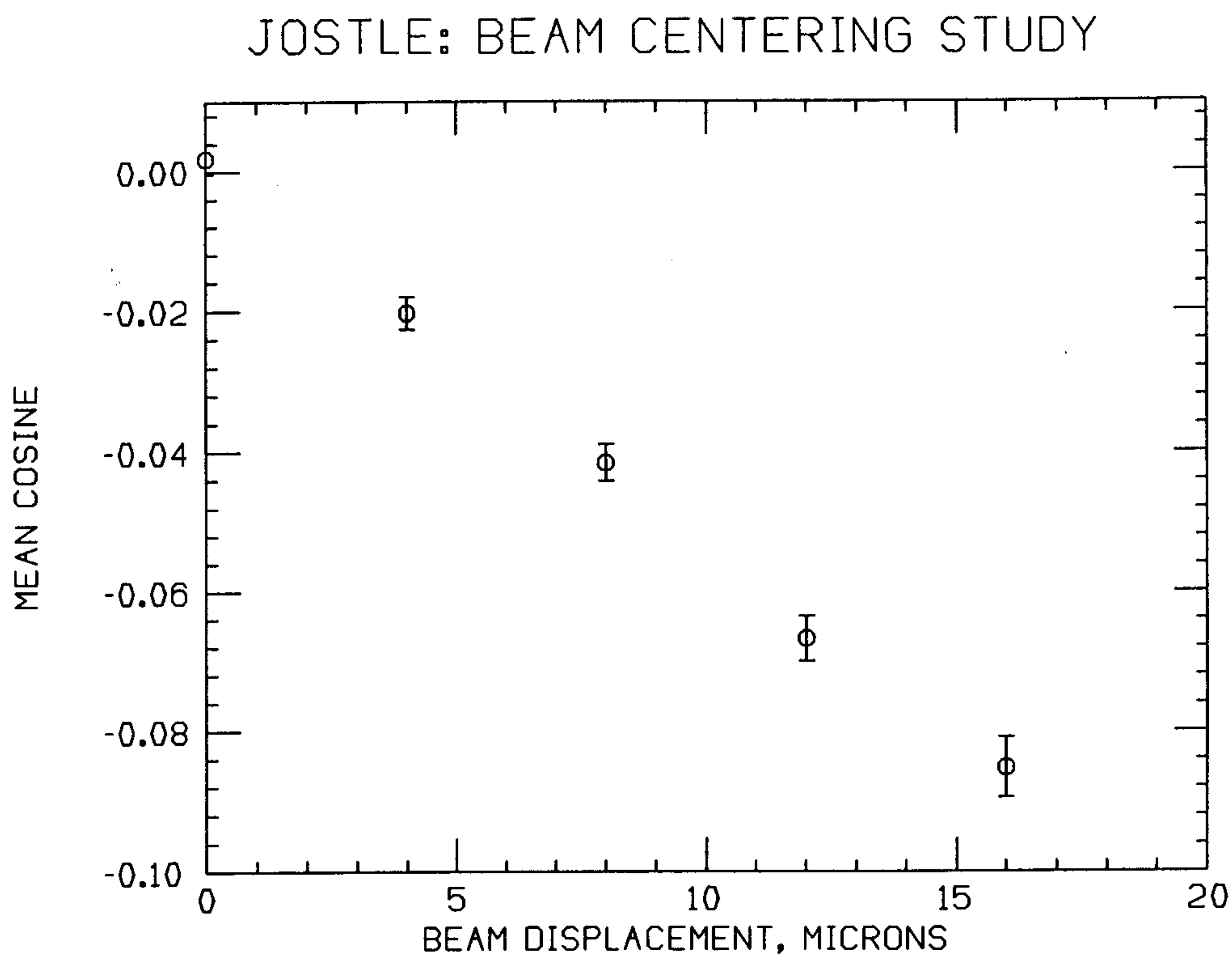

JOSTLE: BEAM CENTERING STUDY
MEAN COSINE
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
0
5
10
15
20
BEAM DISPLACEMENT, MICRONS

FIGURE 2.

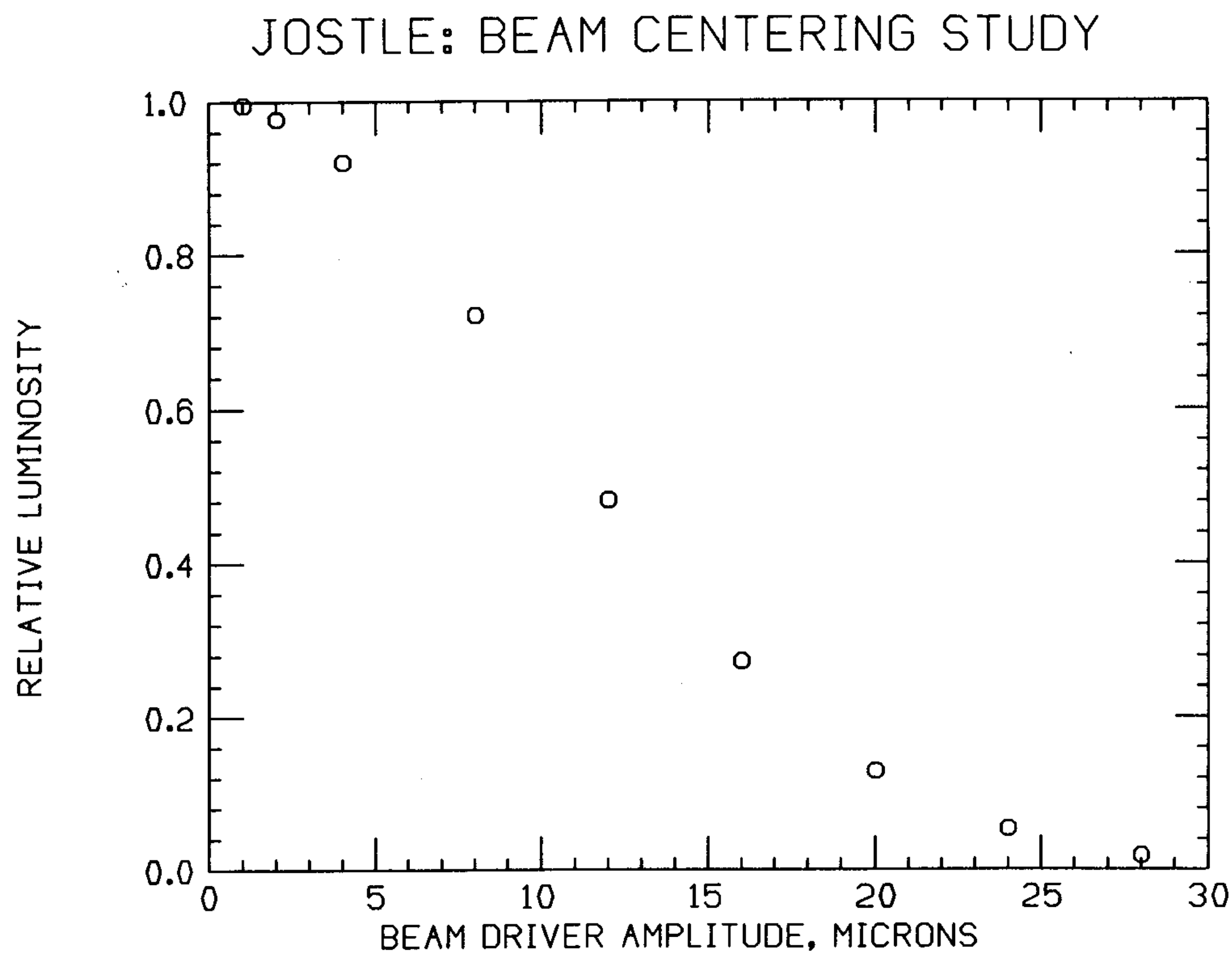

JOSTLE: BEAM CENTERING STUDY
RELATIVE LUMINOSITY
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
BEAM DRIVER AMPLITUDE, MICRONS

FIGURE 3.

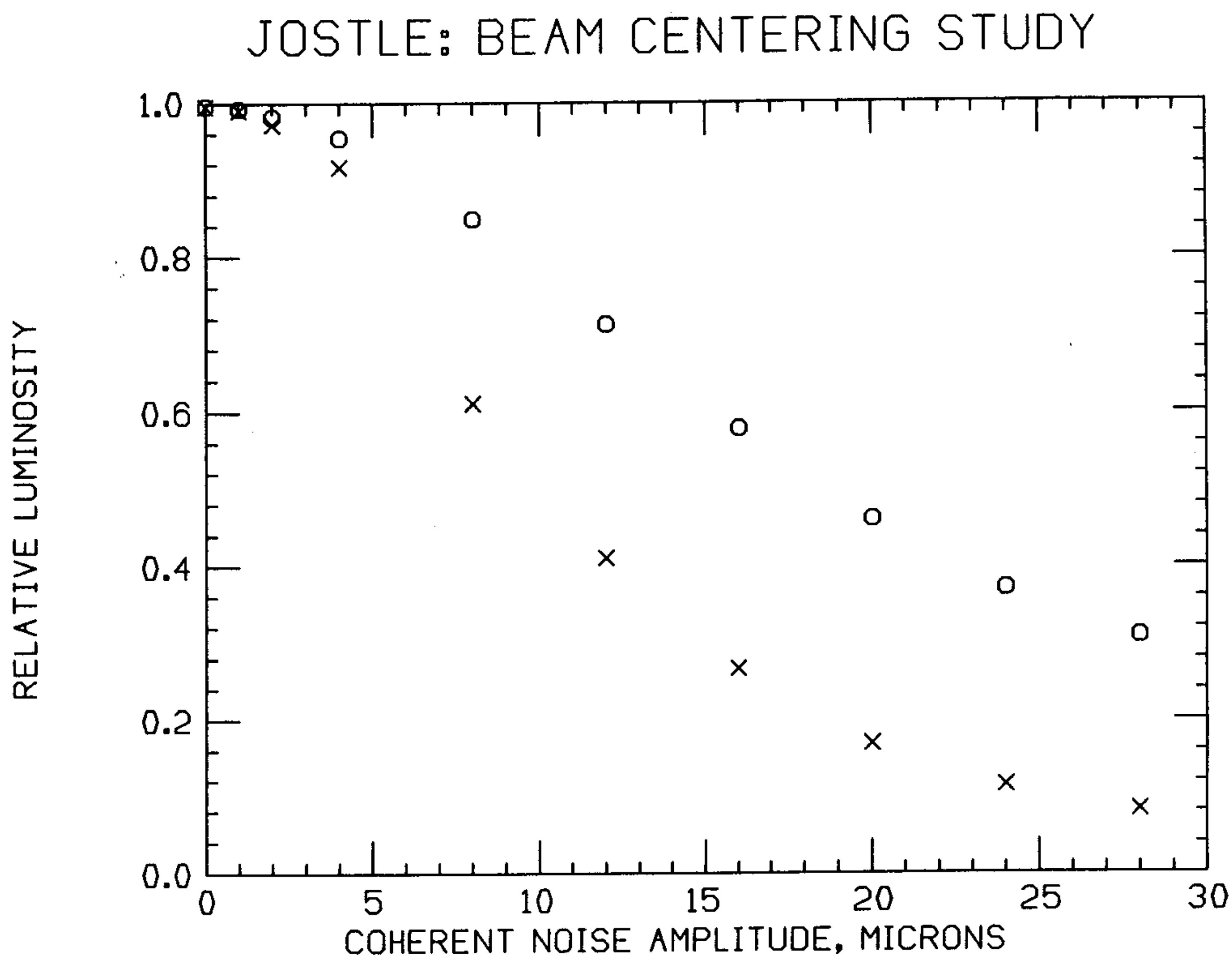

JOSTLE: BEAM CENTERING STUDY
RELATIVE LUMINOSITY
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
COHERENT NOISE AMPLITUDE, MICRONS

FIGURE 4.

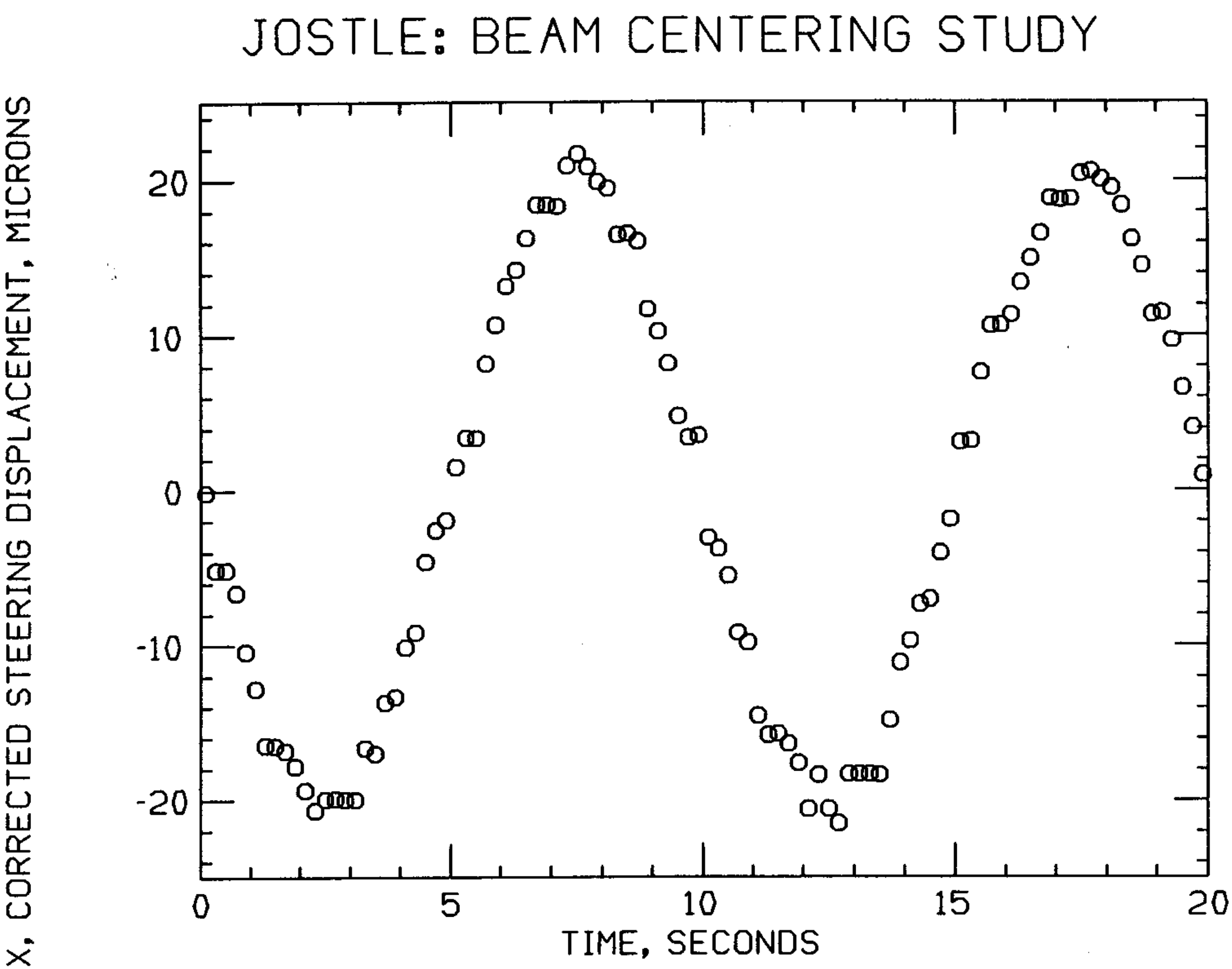

JOSTLE: BEAM CENTERING STUDY
X, CORRECTED STEERING DISPLACEMENT, MICRONS
20
10
0
-10
-20
0
5
10
15
20
TIME, SECONDS

FIGURE 5

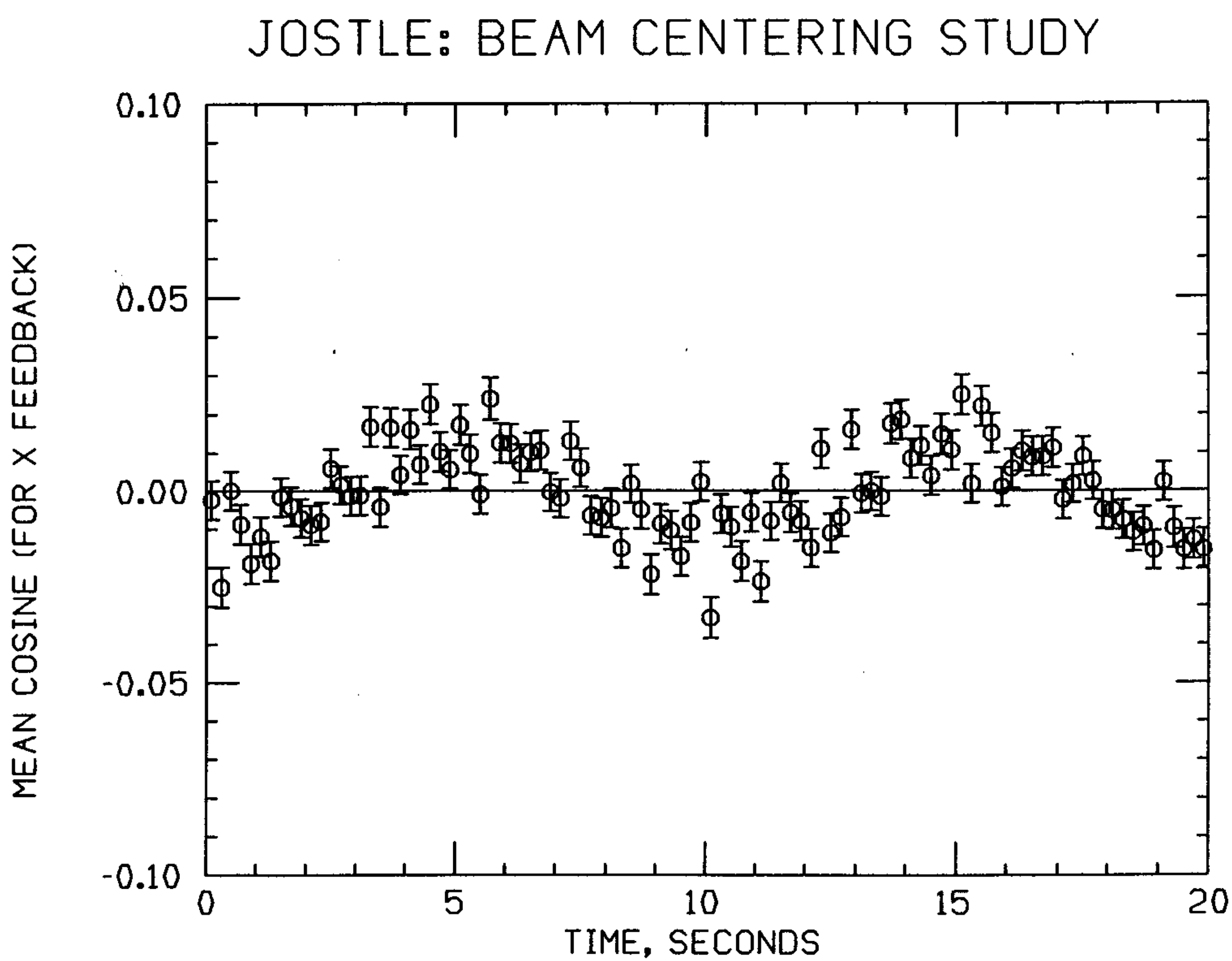

JOSTLE: BEAM CENTERING STUDY
0.10
0.05
0.00
-0.05
-0.10
MEAN COSINE (FOR X FEEDBACK)
0
5
10
15
20
TIME, SECONDS

FIGURE 6

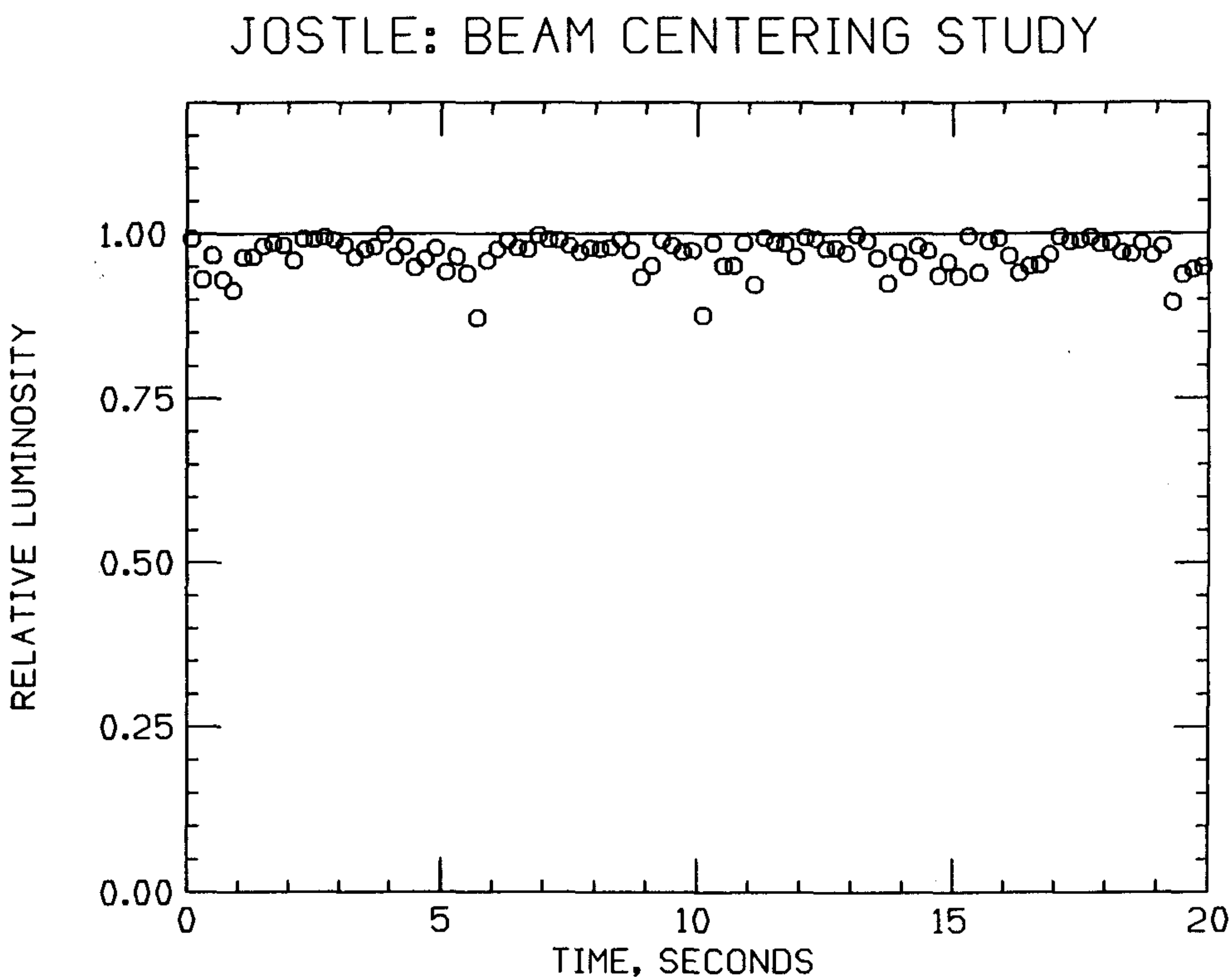

JOSTLE: BEAM CENTERING STUDY
RELATIVE LUMINOSITY
1.00
0.75
0.50
0.25
0.00
0
5
10
15
20
TIME, SECONDS

FIGURE 7