Test Report 126-MOPA #104

by

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1. Performance

1.1. Performance Target Specifications as per LIGO-E970055-02-D

Parameter	*Specification*
1. Power in circular TEM_{00} mode	> 10 W
2. Total power in all non-TEM_{00} modes	< 1 W ($M_{horizontal}$ x $M_{vertical}$ < 1.1)
3. Relative spot size fluctuations, δw/ w	< 2 % peak-to-peak
Relative Power Fluctuations, δP(f)/ P:	
4. Drift over 24 hours	< 1 % peak-to-peak
5. Drift over 500 hours	< 3 % peak-to-peak
6. 1-100 Hz	< [-100 + 40 log(100 Hz/ f)] dB/ Hz
7. 100 Hz - 10 kHz	< -100 dB/ Hz
8. 10 kHz - 3 MHz	< -120 dB/ Hz
9. 10 MHz	< -163 dB/ Hz (within 2 dB of the shot noise limit for 10 mA photodetected current)
Relative Power Fluctuations, δP(f)/ P, at 60 Hz Line Frequency and Harmonics:	
10. 60 Hz and 120 Hz	< 1 x 10^{-5} rms
11. Between 150 Hz and 10 kHz	< 1 x 10^{-5} rms
12. Between 10 kHz and 3 MHz	< 2.4 x 10^{-6} rms
13. Relative power fluctuations, δP(f)/ P, at Model 126 power supply switching frequency (~80 kHz) and power amplifier power supply switching frequency	< 2 x 10^{-5} rms
Frequency Fluctuations:	
14. Between 40 Hz and 100 Hz	< [54 + 50 log(100 Hz/ f)] dB Hz^2 / Hz
15. Between 100 Hz and 10 kHz	< [54 + 20 log(100 Hz/ f)] dB Hz^2 / Hz

Parameter	*Specification*
Frequency Drift:	
16. At constant ambient temperature	< 50 MHz/ hour
17. At constant ambient temperature	< 1 GHz/ month
18. Per degree ambient temperature change	< 30 MHz
Frequency-to-Intensity Conversion:	
19. Fractional power change (W/W) per Hz of frequency change	$< 2 \times 10^{-10}$
Relative Pointing Angle Fluctuations, $\delta\theta/ (\theta_d/ 2)$, (divergence half angle, $\theta_d/ 2 = \lambda/ (\pi \times w_0)$):	
20. Drift over 24 hours	$< 2.5 \times 10^{-2}$ peak-to-peak
21. 40 Hz to 150 Hz	< [-110 + 40 log(150 Hz/ f)] dB/ Hz
22. > 150 Hz	< -110 dB/ Hz
Relative Transverse Position Fluctuations, $\delta x/ w$:	
23. Drift over 24 hours	$< 2.5 \times 10^{-2}$ peak-to-peak
24. 40 Hz to 150 Hz	< [-110 + 40 log(150 Hz/ f)] dB/ Hz
25. > 150 Hz	< -110 dB/ Hz
26. Polarization extinction ratio	> 300:1
27. Electromagnetic interference (EMI) emissions	In compliance with CE mark, EN 55011 Class A
Reliability:	
28. Mean time between failure (MTBF)	> 10,000 hours
29. Minimum time between required beam alignment adjustment	> 2,500 hours

1.2. 126-MOPA #103 Measured Performance

		Meets Specification ?		
Parameter	*Measured Performance*	Yes	No	Comment
1. Power in circular TEM_{00} mode	11 W	(x)		beam not circular;
2. Total power in all non-TEM_{00} modes	0.6 W ($M_{horizontal}$ = 1.02, $M_{vertical}$ = 1.03)	x		
3. Relative spot size fluctuations, $\delta w/ w$	horizontal: 1.1±1.0 % peak-to-peak vertical: 1.4±1.0 % peak-to-peak	x x		300 samples at 1 sample per second;
Relative Power Fluctuations, $\delta P(f)/ P$:				
4. Drift over 24 hours	0.75±1.0 % peak-to-peak	x		
5. Drift over 500 hours	not measured			
6. 1-100 Hz	see Fig. 1	x		
7. 100 Hz - 10 kHz	see Fig. 1	x		
8. 10 kHz - 3 MHz	see Fig. 1	(x)		except 10-12 kHz;
9. 10 MHz	see Fig. 1	x		
Relative Power Fluctuations, $\delta P(f)/ P$, at 60 Hz Line Frequency and Harmonics:				
10. 60 Hz and 120 Hz	4.07×10^{-6} & 3.60×10^{-6} rms	x		
11. Between 150 Hz and 10 kHz	3.22×10^{-6} rms at 180 Hz	x		
12. Between 10 kHz and 3 MHz	undetectable (at 0.3 Hz bandwidth) 60 Hz harmonics above 180 Hz	x		see Fig. 1
13. Relative power fluctuations, $\delta P(f)/ P$, at Model 126 power supply switching frequency (~80 kHz) and power amplifier power supply switching frequency	3.10×10^{-6} rms near 82 kHz	x		

		Meets Specification ?		
Parameter	*Measured Performance*	Yes	No	Comment
Frequency Fluctuations:				
14. Between 40 Hz and 100 Hz	see Fig. 2	x		slightly exceeding specification above 7 kHz
15. Between 100 Hz and 10 kHz	see Fig. 2	(x)		
Frequency Drift:				
16. At constant ambient temperature (MHz/hour)	not measured	?		
17. At constant ambient temperature (MHz/month)	not measured	?		
18. Per degree ambient temperature change	not measured	?		
Frequency-to-Intensity Conversion:				
19. Fractional power change (W/W) per Hz of frequency change	see Fig. 3		x	
Relative Pointing Angle Fluctuations, $\delta\theta/(\theta_d/2)$, (divergence half angle, $\theta_d/2 = \lambda/(\pi \times w_0)$):				data are a superposition of relative transverse position and pointing angle fluctuations;
20. Drift over 24 hours	horizontal: $< 0.8 \times 10^{-2}$ peak-to-peak	x		
	vertical: $< 3.6 \times 10^{-2}$ peak-to-peak		x	room temp. fluctuation
21. 40 Hz to 150 Hz	horizontal: see Fig. 4-1	(x)		except near 138 Hz horizontal;
	vertical: see Fig 4-3	x		
22. > 150 Hz	horizontal: see Fig. 4-2	x		
	vertical: see Fig 4-4	(x)		except 825-870 Hz vertical

		Meets Specification ?		
Parameter	*Measured Performance*	Yes	No	Comment
Relative Transverse Position Fluctuations, $\delta x / w$:				data are a superposition of relative transverse position and pointing angle fluctuations;
23. Drift over 24 hours	horizontal: $< 0.8 \times 10^{-2}$ peak-to-peak vertical: $< 3.6 \times 10^{-2}$ peak-to-peak	x	x	
24. 40 Hz to 150 Hz	horizontal: see Fig. 4-1 vertical: see Fig 4-3	(x) x		except near 138 Hz horizontal;
25. > 150 Hz	horizontal: see Fig. 4-2 vertical: see Fig 4-4	x (x)		except 825-870 Hz vertical
26. Polarization extinction ratio	> 10,000:1	x		
27. Electromagnetic interference (EMI) emissions	Built to be in compliance with CE mark, EN 55011 Class A (not tested)	x		not tested
Reliability:				MO diode current 34 % below manufacturer's Iop, PA diode current 13 % below manufacturer's Iop
28. Mean time between failure (MTBF)	TBD	?		
29. Minimum time between required beam alignment adjustment	TBD	?		

2. Configuration

2.1. Configuration Target Specification as per LIGO-E970055-02-D

Parameter	*Specification*
30. Type of laser	Nd^{3+}:YAG
31. Wavelength	1064 nm
32. Optical scheme	Master Oscillator Power Amplifier, double-pass
33. Amplifier pumping	8 x 20-W diode bar, direct-coupled, side pumped
Frequency Control: 34. Thermal tuning range, continuous 35. Thermal tuning range, total 36. Thermal tuning rate 37. Piezo tuning range, ±15 V 38. Piezo response bandwidth, small signal	 10 GHz 30 GHz 1 GHz/ sec 30 MHz > 30 kHz
39. Warm-up time	< 1 hour
Laser head, mechanical: 40. Support structure 41. Modules/ components 42. Beam height above support structure 43. Cover 44. Total laser height 45. Distance from laser head to power supplies	 2 ft. x 2 ft., ¼ in.-20 tapped holes on 1 in. square grid a. Model 126-1064-700 master oscillator b. Power amplifier, sealed c. Coupling and beam control optics TBD ±0.05 in. Removable dust protective cover, metal < 1 ft. Up to 50 ft.

Parameter	*Specification*
Laser head, optical:	
46. Output beam waist spot size, w_0	0.25 mm TBD ±0.1 mm
47. Output beam waist location	TBD ±50 mm from output aperture
Laser chiller:	
48. Type	Low-temperature, bath circulator
49. Manufacturer, Model	Neslab, RTE-140M
50. Cooling capacity	600 W at 10 °C, at ambient temp. of 20 °C
51. Pumping capacity	0.9 gpm through 100 ft. length of 3/8 in. ID hose
52. Dimensions (h x w x d)	66.0 cm x 31.4 cm x 48.3 cm (> 12 in. clearance at front and rear for ventilation)
53. Distance from laser head to chiller	Up to 50 ft.
54. Distance from chiller microprocessor controller to chiller	Up to 50 ft.
55. Laser safety	In compliance with federal register 21 CFR 1040.10 & 1040.11 laser safety standard
56. Transportability	Transportable by commercial carrier without performance degradation

2.2. 126-MOPA #103 Configuration

		Meets Specification ?		
Parameter	*Configuration*	Yes	No	Comment
30. Type of laser	Nd^{3+}:YAG	x		
31. Wavelength	1064 nm	x		
32. Optical scheme	Master Oscillator Power Amplifier, double-pass	x		
33. Amplifier pumping	8 x 20-W diode bar, direct-coupled, side pumped	x		
Frequency Control:				
34. Thermal tuning range, continuous	10 GHz	x		
35. Thermal tuning range, total	30 GHz	x		
36. Thermal tuning rate	1 GHz/ sec	x		
37. Piezo tuning range, ±10 V	DC: 5.9 MHz/V AC: 5.9 MHz/V	x		
38. Piezo response bandwidth, small signal	> 30 kHz	x		
39. Warm-up time	< 1 hour	x		
Laser head, mechanical:				
40. Support structure	2 ft. x 2 ft., ¼ in.-20 tapped holes on 1 in. square grid	x		
41. Modules/ components	a. Model 126-1064-700 master oscillator b. Power amplifier, sealed c. Coupling and beam control optics	x		
42. Beam height above support structure	2.35 in. ±0.05 in.	x		
43. Cover	Removable dust protective cover, metal	x		
44. Total laser height	8.2 in. ±0.2 in.	x		
45. Distance from laser head to power supplies	Up to 50 ft.	x		

		Meets Specification ?		
Parameter	*Configuration*	Yes	No	Comment
Laser head, optical:				
46. Output beam waist spot size, w_0	horizontal: 0.18 mm ±0.1 mm vertical: 0.21 mm ±0.1 mm	x		
47. Output beam waist location	horizontal: +47 mm ±20 mm from output aperture (outside laser) vertical: -74 mm ±20 mm from output aperture (inside laser)	x		
Laser chiller:				
48. Type	Low-temperature, bath circulator	x		
49. Manufacturer, Model	Neslab, RTE-140M	x		
50. Cooling capacity	600 W at 10 °C, at ambient temp. of 20 °C	x		
51. Pumping capacity	0.9 gpm through 100 ft. length of 3/8 in. ID hose	x		
52. Dimensions (h x w x d)	66.0 cm x 31.4 cm x 48.3 cm (> 12 in. clearance at front and rear for ventilation)	x		
53. Distance from laser head to chiller	Up to 50 ft.	x		
54. Distance from chiller microprocessor controller to chiller	Up to 50 ft.	x		
55. Laser safety	In compliance with federal register 21 CFR 1040.10 & 1040.11 laser safety standard	x		
56. Transportability	May require minor realignment when transported by commercial carrier		x	

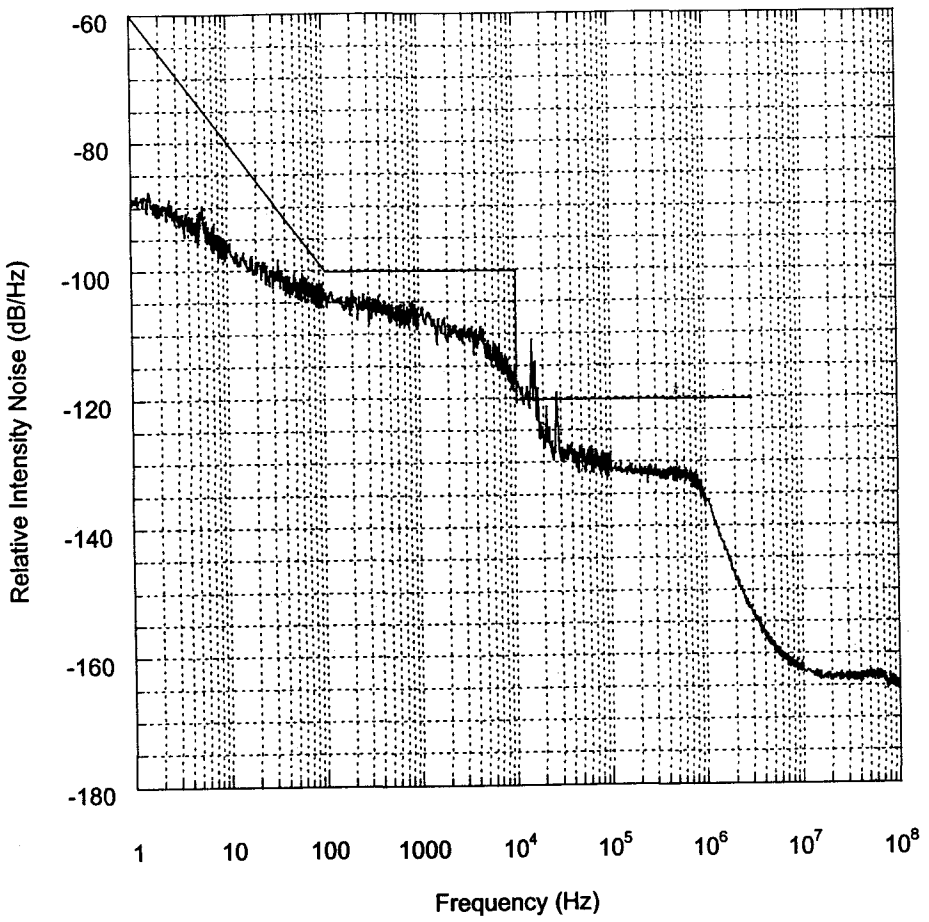

Fig. 1. Measured relative intensity noise of the amplified output at 10 mA photodetected current. The straight line shows specification 6, 7 and 8 of LIGO-E970055-02-D.

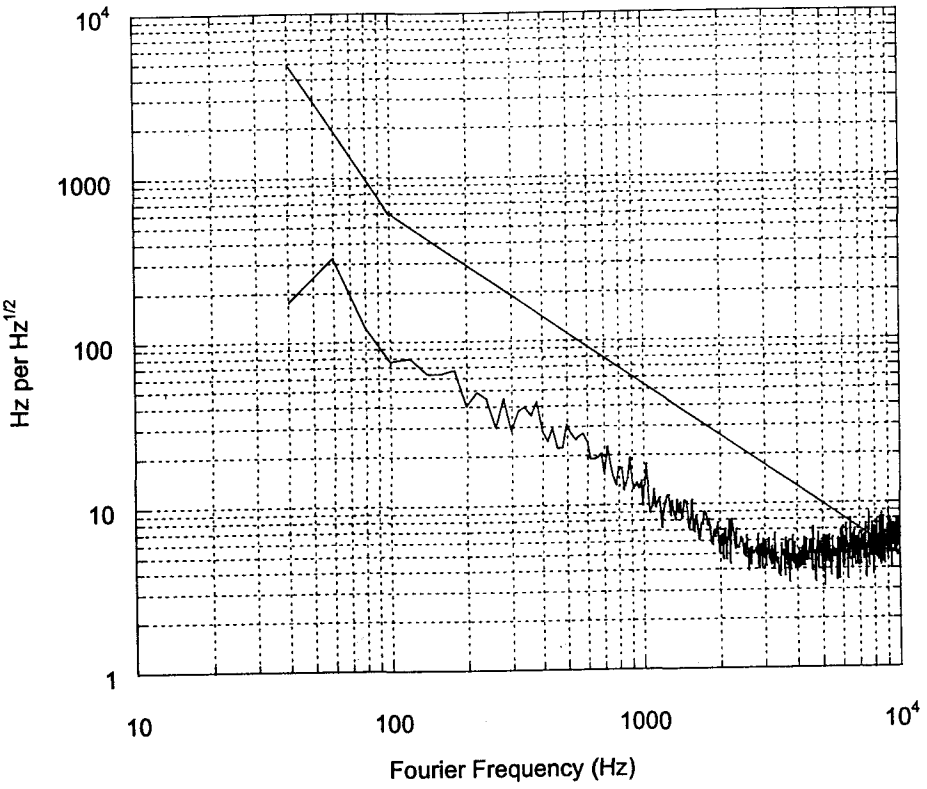

Fig. 2. Measured phase noise of the amplified output. The straight line shows specifications 14 and 15 of LIGO-E970055-02-D.

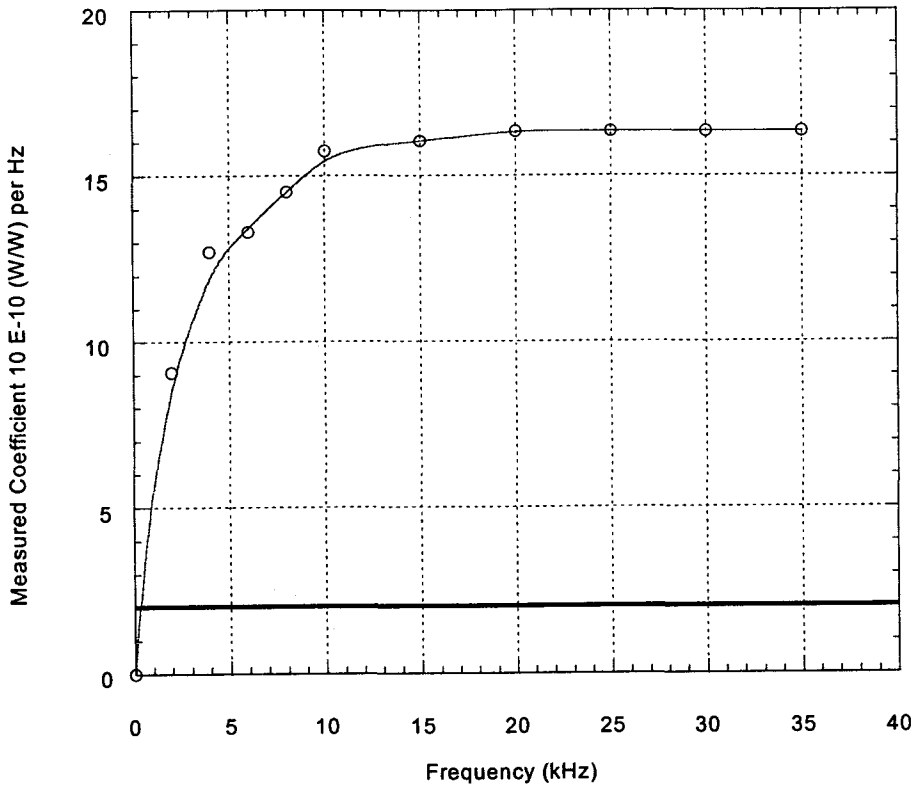

Fig. 3. Measured fractional power change (W/W) per Hz of frequency change. The straight line shows the coefficient defined in specification 19 of LIGO-E970055-02-D.

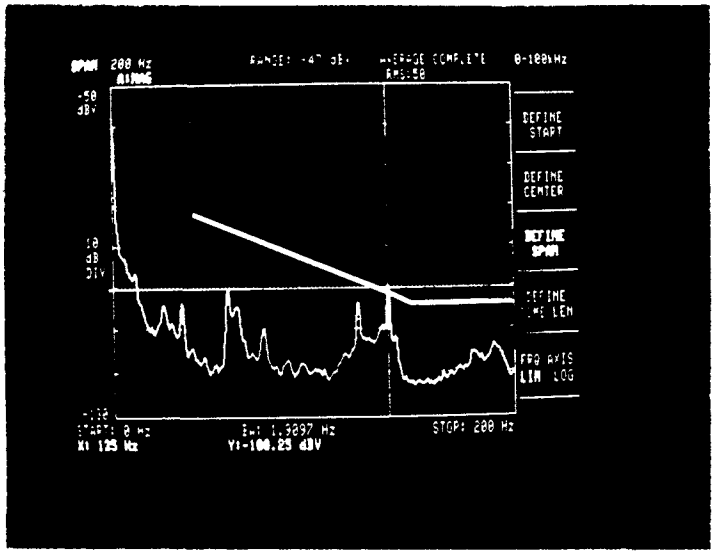

Fig. 4-1. Beam relative pointing angle and transverse position fluctuations, horizontal component, 0 - 200 Hz. The thick white line shows specifications 21 and 22 of LIGO-E970055-02-D in units dBVolt.

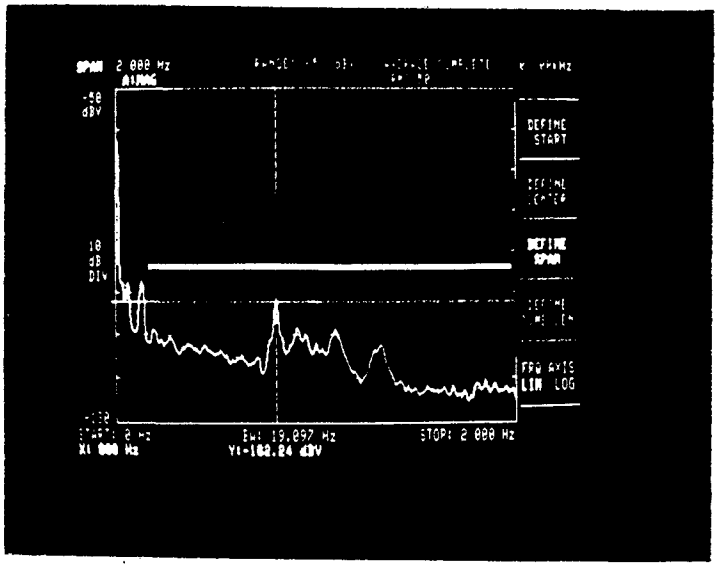

Fig. 4-2. Beam relative pointing angle and transverse position fluctuations, horizontal component, 0 - 2000 Hz. The thick white line shows specifications 21 and 22 of LIGO-E970055-02-D in units dBVolt.

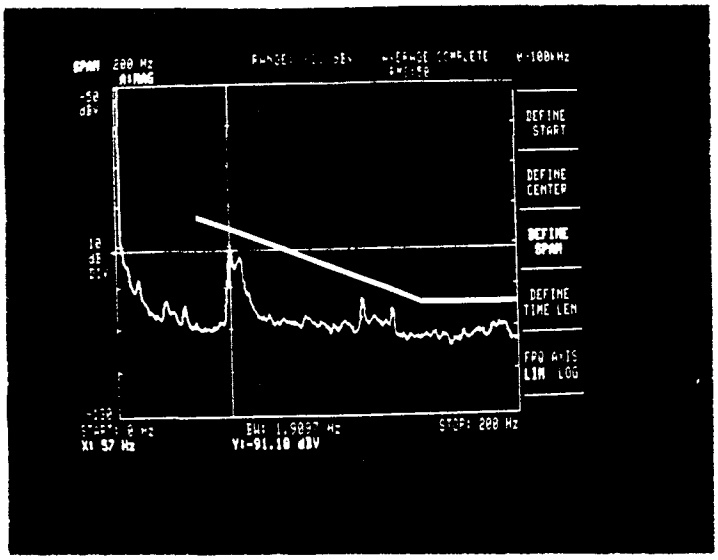

Fig. 4-3. Beam relative pointing angle and transverse position fluctuations, vertical component, 0 - 200 Hz. The thick white line shows specifications 21 and 22 of LIGO-E970055-02-D in units dBVolt.

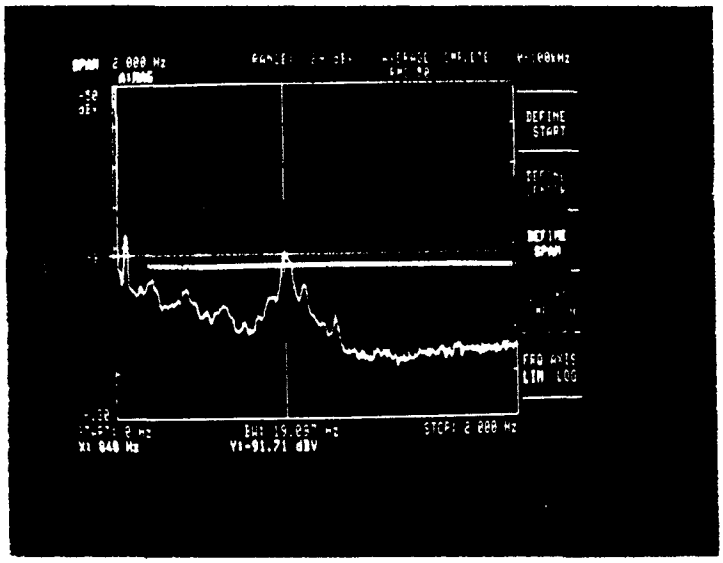

Fig. 4-4. Beam relative pointing angle and transverse position fluctuations, vertical component, 0 - 2000 Hz. The thick white line shows specifications 21 and 22 of LIGO-E970055-02-D in units dBVolt.