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Test method for performance parameters of optical frequency comb in precision optical frequency measurement

精密光频测量中光学频率梳性能参数测试方法

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1 Scope

The document describes the test environment requirements, the requirements for the configuration of the test equipment, the test methods and the test report for the performance parameters of an optical frequency comb used in precision optical frequency measurement applications.

It applies to the testing of the performance parameters of the optical frequency combs used in precision optical frequency measurement systems.

2 Normative references

The content of the following documents constitutes, through normative reference in the text, indispensable provisions of this document. For dated references, only the edition corresponding to that date applies; for undated references, the latest edition, including all amendments, applies.

GB/T 15313-2008 Laser terminology.

GB/T 25915.1-2021 Cleanrooms and associated controlled environments - Part 1: Classification of air cleanliness by particle concentration.

3 Terms and definitions

The terms and definitions given in GB/T 15313-2008, together with the following, apply to the document.

3.1 repetition rate: the number of laser pulses emitted per second by a pulsed laser.

3.2 carrier-envelope offset frequency: the frequency corresponding to the phase change between the carrier envelope of the pulsed laser and the optical carrier.

3.3 optical frequency comb: an optical signal generation system in which the repetition rate and the carrier-envelope offset frequency are precisely controllable.

3.4 tuning range of repetition rate: the output frequency range of the repetition rate of the optical frequency comb.

3.5 tuning range of carrier-envelope offset frequency: the output frequency range of the carrier-envelope offset frequency of the optical frequency comb.

3.6 signal-to-noise ratio of carrier-envelope offset frequency: the ratio of signal to noise of the carrier-envelope offset frequency of the optical frequency comb.

3.7 line width of carrier-envelope offset frequency: the full width at half maximum of the carrier-envelope offset frequency of the optical frequency comb.

3.8 average power of single comb tooth: the mean value of the power of a single comb tooth of the optical frequency comb under a specified wavelength condition.

3.9 flatness of output optical spectrum: the difference between the maximum power and the minimum power of the output spectrum of the optical frequency comb within a specified wavelength range.

3.10 allan deviation: one over the square root of two times the root mean square of the difference between the mean frequency values in two adjacent sampling intervals of duration tau. Note: for M frequency measurement data the allan deviation is calculated by formula (1); the legend of that formula gives the allan deviation, the sampling time, the mean frequency deviation and the number of frequency samples.

3.11 instability of repetition rate frequency: the degree of random fluctuation of the repetition rate of the optical frequency comb. Note: it is characterised by means of the allan deviation.

3.12 instability of carrier-envelope offset frequency: the degree of random fluctuation of the carrier-envelope offset frequency of the optical frequency comb. Note: it is characterised by

means of the allan deviation.

3.13 line width of comb teeth: the full width at half maximum of the comb teeth of the optical frequency comb under specified wavelength and resolution conditions.

4 Test environment requirements

The environment of the test room is kept air filtered and free of dust, and the residual dust is required to meet the ISO class 4 cleanliness requirement defined in GB/T 25915.1-2021.

The relative humidity of the test room environment is below 65 %, the temperature is 23 °C +/- 3 °C, and the temperature fluctuation during verification is below 1 °C.

5 Requirements for the configuration of the test equipment

The measuring equipment is required to satisfy the following.

a) The measuring range and the accuracy of the measuring equipment meet the corresponding test requirements.

b) The test wavelength range of the measuring equipment covers the wavelength range of the optical frequency comb under test.

c) The instruments and the equipment are properly earthed during the test.

d) The supply voltage, the ripple and the noise used in the test meet the requirements of the instruction manual of the test equipment and the requirements for the use of the optical frequency comb.

6 Test methods

6.1 Tuning range of repetition rate. The test proceeds through the following steps. a) The optical frequency comb under test and the test instruments are warmed up. b) The test system is connected as shown in Figure 1, with the amplitude of the repetition rate signal within the range from minus 20 dBm to 0 dBm and the signal-to-noise ratio above 20 dB at a resolution of 300 kHz, the optical frequency comb and the spectrum analysis equipment being connected with a 50 ohm coaxial cable. c) The repetition rate control device is set, the repetition rate of the optical frequency comb under test is varied, and the maximum and the minimum repetition rate values of each run are recorded with no fewer than two significant figures, the measurement being repeated n times with n not less than 5; the means of the n measurements are calculated with formulas (2) and (3) to obtain the maximum and the minimum repetition rate, in kilohertz (kHz). d) The tuning range of the repetition rate is calculated with formula (4), in kilohertz (kHz).

6.2 Tuning range of carrier-envelope offset frequency. The test proceeds through the following steps. a) The optical frequency comb under test and the test instruments are

warmed up. b) The test system is connected as shown in Figure 2, with the amplitude of the carrier-envelope offset frequency signal within the range from minus 20 dBm to 0 dBm and the signal-to-noise ratio above 20 dB at a resolution of 300 kHz, the optical frequency comb and the spectrum analysis equipment being connected with a 50 ohm coaxial cable. c) The control device of the carrier-envelope offset frequency is set, that frequency is varied, and its maximum and minimum values are recorded with no fewer than two significant figures, the measurement being repeated n times with n not less than 5; the means of the n measurements are calculated with formulas (5) and (6), in kilohertz (kHz). d) The tuning range of the carrier-envelope offset frequency is calculated with formula (7), in kilohertz (kHz).

6.3 Signal-to-noise ratio of carrier-envelope offset frequency. With the carrier-envelope offset frequency in the unlocked state, the test proceeds through the following steps. a) The test system is connected as shown in Figure 2, the optical frequency comb and the spectrum analysis equipment being connected with a 50 ohm coaxial cable. b) With the spectrum analysis equipment set to a resolution of 300 kHz, the peak power of the carrier-envelope offset frequency signal and the noise floor power at 10 MHz from the carrier-envelope offset frequency, or at one quarter of the repetition rate, are recorded with no fewer than two significant figures; the measurement is repeated n times with n not less than 5 and the means of the n measurements are calculated with formulas (8) and (9), in decibel-milliwatts (dBm). c) The signal-to-noise ratio of the carrier-envelope offset frequency of the optical frequency comb is calculated with formula (10), in decibels (dB).

6.4 Line width of carrier-envelope offset frequency. With the carrier-envelope offset frequency in the unlocked state, the test proceeds through the following steps. a) The test system is connected as shown in Figure 2, the optical frequency comb and the spectrum analysis equipment being connected with a 50 ohm coaxial cable. b) With the spectrum analysis equipment, the full width at half maximum of the carrier-envelope offset frequency signal is measured, the resolution of the spectrum analysis equipment being set finer than one third of the line width of that signal.

6.5 Average power of single comb tooth. The test of the average power of a single comb tooth of the optical frequency comb at a given wavelength proceeds through the following steps. a) The optical frequency comb under test and the test instruments are warmed up. b) The optical frequency comb and the optical spectrum analyser are connected with an ordinary single-mode fibre of the corresponding waveband. c) The resolution of the optical spectrum analyser is set to 0.1 nm and the complete output spectral curve of the optical frequency comb is measured, n spectrum measurements being completed with n not less than 5. d) The measured spectral intensity is normalised, the point of greatest spectral intensity being set to 1, the spectral integral area of each run is calculated, and the mean integral area of the output spectrum is calculated with formula (11), in nanometres (nm). e) The output power of the optical frequency comb is measured with a thermal power meter, the measurement being repeated n times with n not less than 5, and the mean output