a) substantial absorption of radiation in the cavity-lengthening fibre;

b) pulse repetition period reaching values comparable to the upper state lifetime of the active medium of the laser (~1 ms for ytterbium-doped silica fibres [27]).

In the studied laser, the pulse repetition period amounted to 24 μs. Accordingly, it is likely possible to slow down the pulse repetition by more than an order of magnitude before limitation b) kicks in. Such cavity elongation (by more than an order of magnitude) is also possible if the cavity-lengthening fibre with relatively low losses at the generation wavelength is chosen (*e.g.* with attenuation not exceeding 0.5 dB/km). In such a case, it is not unreasonable to expect pulse energies at the output of a passive mode-locked long fibre master oscillator reaching 100 μJ and even higher. One of the probable technical obstacles to achievement of ultra-high pulse energies directly at the output of a fibre master oscillator is limited radiation damage threshold of the employed fibre components.

3. Conclusion

The present work for the first time demonstrates that record-high pulse energies exceeding 12 μJ can be obtained directly at the output of passive mode-locked Yb-based long fibre oscillator without resorting to additional fibre amplifiers. Mode locking was implemented with the help of a nonlinear amplifying loop mirror, while nonlinear effects in a 2.5-km cavity-lengthening fibre were substantially reduced through a specially designed master oscillator layout, in which intra-cavity radiation power may be significantly different in different parts of the cavity. The developed layout using an intra-cavity power management solution, which is proposed here for the first time, opens prospects of further pulse energy enhancement in passive mode-locked long fibre master oscillators (reaching 100 μJ and higher), which was only limited in the present work by the available pump power and the length of the used fibre.

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