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Optical resonators for long pulse Nd:YAG laser with thermal effects

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Abstract. Experiments on laser beam divergence long-pulse Nd:YAG laser using a different kinds of optical resonators has been performed. The variation of the thermal focal length during long-pulse pumping (up to ten milliseconds) in Nd:YAG rod was measured using a precise method. A multimode resonator for variable long-pulse laser was designed by using the matrix method and taking into account the thermal lens of the laser rod.

INTRODUCTION

In various applications of variable long-pulse high-energy Nd:YAG laser [1,2], (especially applications which require a constant spot size during the laser pulse), the constant quality of the laser beam is a very important parameter. If a laser rod is pumped homogeneously a parabolic temperature profile, and therefore a refractive index gradient, is built up. The rod behaves like a thick lens with a refractive power D , which increases with the input energy. A resonator with such a thick lens inside was investigated by several authors [3,4] for high input power and high repetition rate. At low repetition (<5 Hz) and high energy input a thermal equilibrium cannot be reached and the rod's focal length increases in time of pumping as the pump proceeds. The variation of the focal length changes the laser beam multimode divergence for usual optical resonators.

The purpose of this paper is to present the results on experimental investigation of thermal effects in Nd:YAG rods pumped with linear flashlamps with variable pulses from 0.5 to 10 milliseconds and pump energy up to 5000 J and the optical resonator designed to compensate thermal effects. In order to improve the laser beam quality some optimal stable and unstable VRM resonators were investigated.

TRANSIENT THERMAL EFFECTS IN MILLISECOND PULSED Nd:YAG LASER

Thermal effects in a Nd:YAG laser rod pumped at high input energy and milliseconds duration are very strong and could affect the behaviour of the laser resonator during the laser pulse. In order to measure the thermal focal length of the active media f_s , we use the optical arrangement presented in Fig. 1. Passing a He-Ne laser probe beam through the rod during pumping we can measure the probe beam intensity in plane P with a photodetector. The active medium is considered as a thick lens. The relation between f' (the equivalent focal length of the optical system formed by laser rod with focal length f_s and lens F, with focal length f_1) and b_s the distance from F_1 to focal plane of the optical system is:

$$b_s = f'_s (1 - d_1 \frac{1/f'_{eq} - 1/f'_1}{1 - d_1/f'_1})$$

Because the precise measurement of b_s is very difficult for the Gaussian beam we used a more precise method [5]. By measuring $I_1(t)$ and $I_2(t)$ intensities of the He-Ne laser beam in two different points belonging to the plane P at the distance z from focal point of the optical system one can determine the variation of the beam spot size $w_D(t)$ at z , using the equation:

$$\frac{k}{w_D(t)} \exp \left[- \left[\frac{w_D(t) \sqrt{\ln \left(\frac{k}{w_D(t) I_2} \right)}}{w_D(t)} \right]^2 \right] - I_1 = 0$$

Knowing $w_D(t)$ we can calculate $f'(t)$ and finally $f_D(t)$.

In our experiments Nd:YAG laser rod has 84mm length, 6.6mm diameter, 1.1% at. concentration of Nd, and $f_f = 500\text{mm}$. The results obtained are presented in Table I.

Table I. Thermal transient focal length.

Duration of pumping pulse Δt (ms)	Pumping energy (J)	I_1 (mV)	I_2 (mV)	$w_D(t)$ (mm)	f_D^{eq} (mm)	Focal length of the rod f_D (mm)
4	315	150	125	15.99	390	1106
7	550	145	120	17.67	371	953
9.5	950	140	110	18.75	353	749
4	315	150	190	18.37	357	779
7	550	140	175	18.72	353	749
9.5	950	130	160	20.29	334	628
4	315	170	130	15.50	397	1202
7	550	160	125	16.22	386	1056
9.5	950	150	110	18.55	355	763

Fig. 2 shows the temporal variation of $I_1(t)$, the He-Ne laser probe beam intensity and one can observe that initial temperature of laser rod is establish after 1.5 seconds. Variations of the laser rod refractive power up to 2m^{-1} were observed when the length of the pumping pulse vary between 0.5 and 10ms at different pumping energies.

Fig.1. Experimental set-up for determination of transient refractive power in Nd:YAG rod.

Fig. 2. Temporal variation of the He-Ne laser probe beam passing the Nd:YAG rod.

EXPERIMENTS USING DIFFERENT OPTICAL RESONATORS

When the resonators of a laser system are designed to provide the desired beam pattern, with the laser rod operated at a specified length pulse, the extent and nature of the lensing behaviour exhibited by the rod must be also taken into account. To find the optimal resonator parameters that maintain the constant quality of laser beam during laser pulse in the case of multimode laser operation with internal variable thermal lens a matrix method was used. The best result in our case was obtained by using a plan-spherical resonator with 0.8 m length and 2 m mirror radius. In such a configuration the Nd:YAG rod (6.6x85mm), pumped with variable pulse length, was placed nearly the output plane mirror. Fig. 3 shows the numerically calculate multimode divergence versus optical power in the plane-spherical resonator for two different resonator lengths. The numerical calculus shows also that this plan-spherical resonator with the laser rod very close to the flat output mirror is the most insensitive to the variations of the refractive power.

The unstable resonators that use radially variable-reflectivity mirrors (VRM) as output couplers were demonstrate [6,7] to be a solution for the generation of high-energy diffraction limited beams with smooth transversal profile. The results obtained by the use of a VRM mirror in stable and unstable resonators are presented.

The reflectivity of a super-Gaussian mirror has the analytical form

$$R(r) = R_0 \exp[-2(r/w_m)^n]$$

where R_0 is the peak reflectivity, r is the radial coordinate, w_m is the spot size, and n is the order of the mirror.

Fig.3. Multimode divergence in plan-spherical resonator (mirror radius 2m) parameter L =resonator's length

A 45cm length resonator operating in the stable and unstable configurations was equipped with variable reflectivity mirrors and with a 39% reflectivity usual mirror. The laser rod was placed 10cm apart from the rear mirror. The results about the

output power and divergence of the beams are presented in Table II. The beam divergence was measured by ASTM 43 method using a 1m focal lens and a SCIENITECH361 powermeter.

Table II. Output power and divergence of the laser beam obtained for stable and unstable resonator configuration. The duration of pumping pulse was 3ms with 5Hz rate of repetition and 150 J pump energy.

Resonator configuration	Output Power (W)	Divergence (mrad)
Plane-plane stable resonator, 39% output coupler.	10.5	4.0
Plane-plane stable resonator, VRM output mirror with $R_0=35\%$, $w_0=1.6\text{mm}$, $n=4.2$.	9.2	3.5
Plane-plane stable resonator, VRM output mirror with $R_0=35\%$, $w_0=1.7\text{mm}$, $n=5$.	8.8	3.2
Unstable configuration with -5m rear mirror and VRM output mirror with $R_0=35\%$, $w_0=1.6\text{mm}$, $n=4.2$.	6.5	< 1
Unstable configuration with -5m rear mirror and VRM output mirror with $R_0=35\%$, $w_0=1.7\text{mm}$, $n=5$.	6.8	< 1

As Table II shows an improved laser beam divergence was observed for VRM stable configuration as compared to usual plane-plane resonator, with only a small decrease of laser pulse energy.

CONCLUSIONS

The thermal transient effect induced in a Nd:YAG laser rod pumped with pulses up to ten milliseconds and energy up to 1000J can be precisely measured by the method described before. By using a matrix method and taking into account the thermal transient effects, the optimal plane-plane resonator which maintain constant the beam quality during the pumping pulse was determined. For the stable configuration the beam quality can be improved by using variable reflectivity mirror as output coupler.

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