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A FREE STREAM JET FOR HIGH POWER DYE LASERS

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A FREE STREAM JET FOR HIGH POWER DYE LASERS[*]

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In recent years, the tunable dye laser has proven to be useful in conducting atomic and molecular spectroscopy,[1] particularly when laser output powers of several hundred milliwatts are satsifactory, and emission linewidth control is the important factor. More recently, tunable lasers have had increasingly widespread use in the field of isotope separation and photochemistry.[2,3] For these applications the desired output powers are considerably higher than those required to perform spectroscopic studies. Tunable dye lasers with powers on the order of many tens of watts to several kW with emission linewidth stability on the order of 1/2 GHz will be required for commercial scale separation processes. To achieve these goals, several dye laser systems, both cw and pulsed, are presently under investigation at Livermore and other laboratories.

This paper will report on the efforts to develop a free stream dye jet for incorporation into an incoherently pumped pulsed dye laser as shown in Fig. 1. For this particular laser head design, the excitation illumination direction, dye solution flow, and laser mode axes are mutually perpendicular. The active dye region is 2 mm thick, 72 mm long and 6 mm in the direction of dye flow.

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The motivation for the development of a free stream jet can be seen from evaluation of the fall off of laser output for high pump powers in an enclosed dye cell. Such an analysis was presented in the previous paper by Peterson, Pease, and Pearson,[4] where the effects of microscopic temperature and velocity fluctuations within the dye solution were observed. Large changes in the index of refraction for high power dye lasers have been observed due to the high temperature gradients present within dye cells. For free jets, the source of these temperature gradients has been eliminated.

However, free jets are not without their own set of problems. The most predominant are the effects of turbulent flow at high jet velocities, the design and fabrication of a jet nozzle to eliminate surface wave instabilities, and the effects of mechanical vibrations from fluid pulsations.

The criteria used for the development of this free jet for an incoherently pumped dye laser were that the surface of the liquid-air interface must not distort the focus of the excitation illumination; the jet must be stable at liquid flow velocities large enough to replace the dye solution in the active volume between every flash of a pulsed laser; and most importantly, the clear aperture as viewed along the laser mode axis must be essentially identical to the stream thickness.

The development of a nozzle and flow system that is capable of establishing a stable free stream jet is quite complex. Although exact analytical solutions to describe the jet velocity profile and surface wave phenomena are difficult to obtain, hydrodynamic models have been used to establish guidelines for an experimental approach.

The nozzle configurations shown in Fig. 2 were evaluated. The first consists of orifice flow with knife edges at the exit, the second is flow from a converging slit, and the third is flow between two long parallel planes with 90° edges at the exit. Testing of these configurations established the magnitude of the effects of several parameters on the production of surface waves on the jet stream, namely: (a) fabrication imperfections of the nozzle, (b) jet end window contacts, (c) hydraulic pulsations and supply plenum turbulence, and (d) air friction.

The configuration shown in Fig. 3, with slot flow between long parallel planes has given the highest quality planar surfaces. As can be seen in this cutaway of the nozzle, the area at the ends where the laser output Brewster windows are located has been enlarged to accomodate the jet fluid that was forming a meniscus on the output windows. This attachment point for the meniscus was moved out because it was creating large surface waves on the planar jet surface. The relief area for this nozzle configuration was experimentally determined.

The quality of the jet planar surfaces was improved by fabricating the nozzle from corrosion resistant materials and obtaining optical quality finishes on the walls and exit edges.

Hydraulic pulsations and fluid turbulence within the flow circuit are created by the fluid pumps. It was found that the pulsations could be greatly reduced by the use of a fluid vibration filter accumulator and a Micropore particle filter. The turbulence was further reduced by placing stainless steel wool in the plenum above the nozzle entry.

Experimental evaluation of the nozzle configurations was performed utilizing a laser interferometer as shown in Fig. 4. The laser mode axis clear aperture was determined as a function of jet velocity and distance from the nozzle exit. The insert photograph shows a typical interferogram of this laser aperture.

Following determination of the jet stream parameters, the nozzle was incorporated into a flashlamp pumped dye laser cavity. For initial testing, Coumarin 314 and 5% Ammonyx in water was used to determine the effect of jet stream velocity on the absorption of the pump light into the dye solution. Figure 5 shows the relative laser output as a function of jet velocity or stream Reynolds number. The point at which output began to decrease coincided with the onset of short wavelength surface waves on the planar surface. This point occurred well above the laminar flow regime. At this maximum condition, a laser repetition rate of 500 Hz can be achieved for a 4 mm laser active region.

Additional testing with this laser configuration as shown in Figure 6, achieved output powers of 225 MW at a repetition rate of 160 Hz, with the input energy being 15.4 J/pulse. This graph shows the power for the laser with the jet stream beginning to peak at a repetition rate near 200 Hz. For this laser head design and a closed dye cell the peak power occurred around 50 Hz.

In conclusion, we can look at what has been shown to date, where improvements can be made and what the limitations of this jet stream may be. First, this jet stream system has produced a planar surface that can be pumped by an incoherent source and operates at higher input energies than the enclosed dye cell in the same configuration. Optical quality of the stream can be maintained well above the lamiar flow transition, therefore allowing streams with several millimeter thicknesses to be operated at high repetition rates. We have shown that by proper nozzle design and fabrication, the laser mode axis clear aperture can be maintained almost identically to the nozzle thickness, and the optical quality of the planar surface can be maintained at high jet stream velocities.

Improvements are still to be made to this type of system. Additional nozzle configurations should be investigated which may allow operation at much higher stream velocities. A further reduction in the upstream fluid pulsations and turbulence would allow improve operations. The limitations of the jet stream are to be determined, particularly the effect on the optical quality of the planar surface from higher stream Reynolds number and friction between the liquid-air interfact at high relative velocity differences. Also, for pulsed laser systems, the effect of shock waves produced from the pulsed light source on the distrotion in the jet stream.

While the jet stream has not yet been optimized for use in high power narrow linewidth lasers, this first step has shown the feasibility of using this concept.

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DEVELOPMENTAL DYE LASER

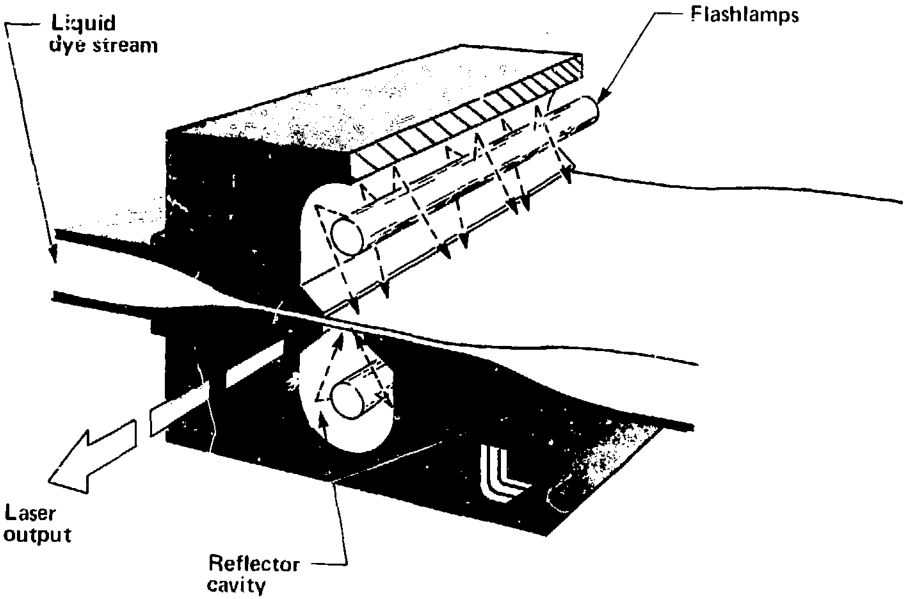
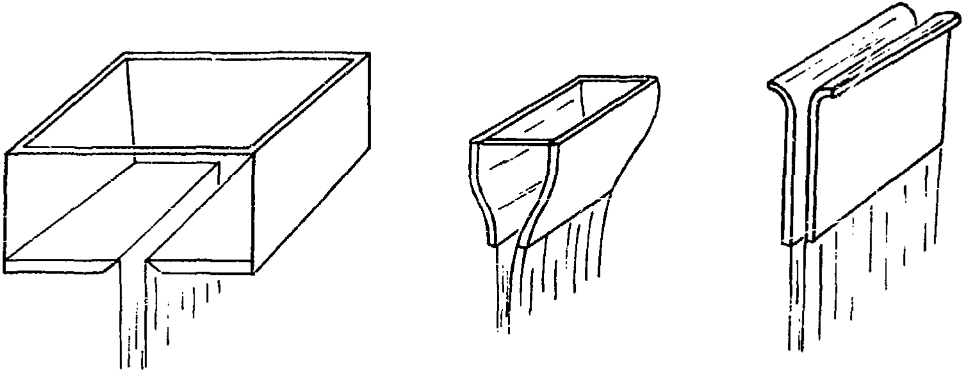


FIGURE 1

JET NOZZLE CONFIGURATIONS



Knife edge orifice

Converging slit

Parallel planes

FIGURE 2

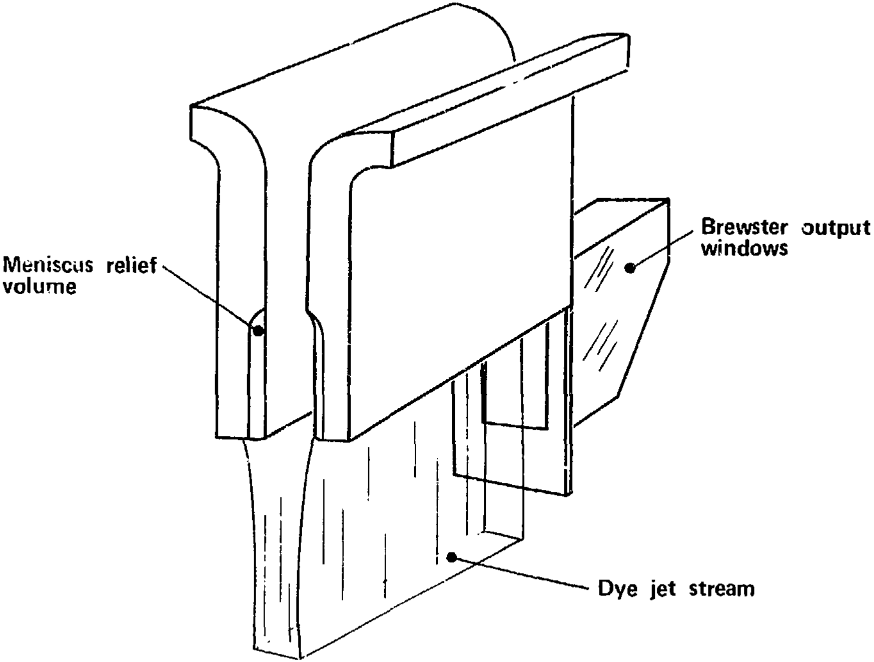

Meniscus relief volume
Brewster output windows
Dye jet stream

FIGURE 3

INTERFEROMETER DIAGNOSTIC APPARATUS

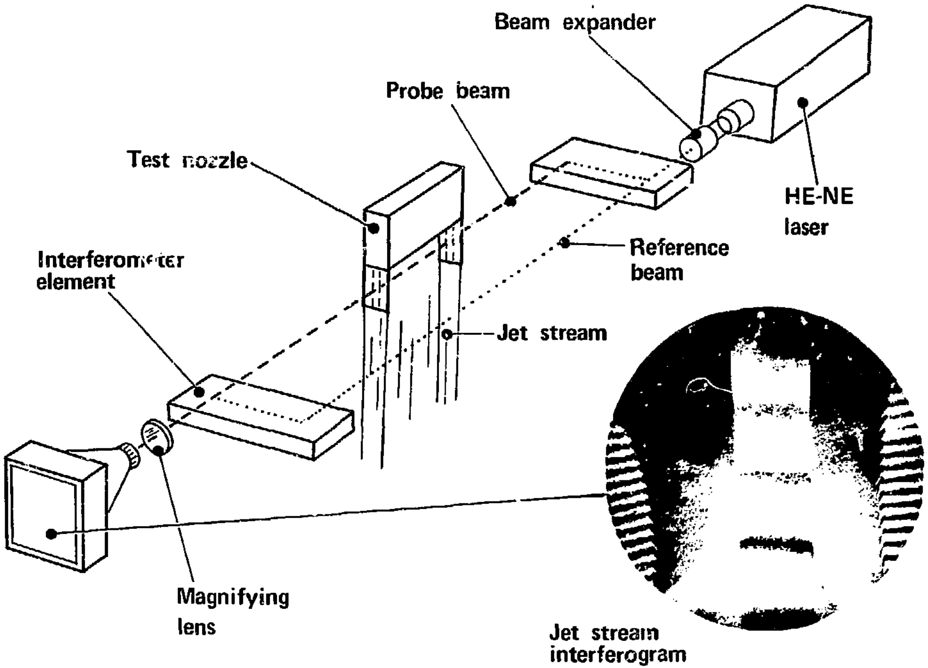


FIGURE 4

EFFECT OF JET STREAM SURFACE QUALITY ON LASER OUTPUT

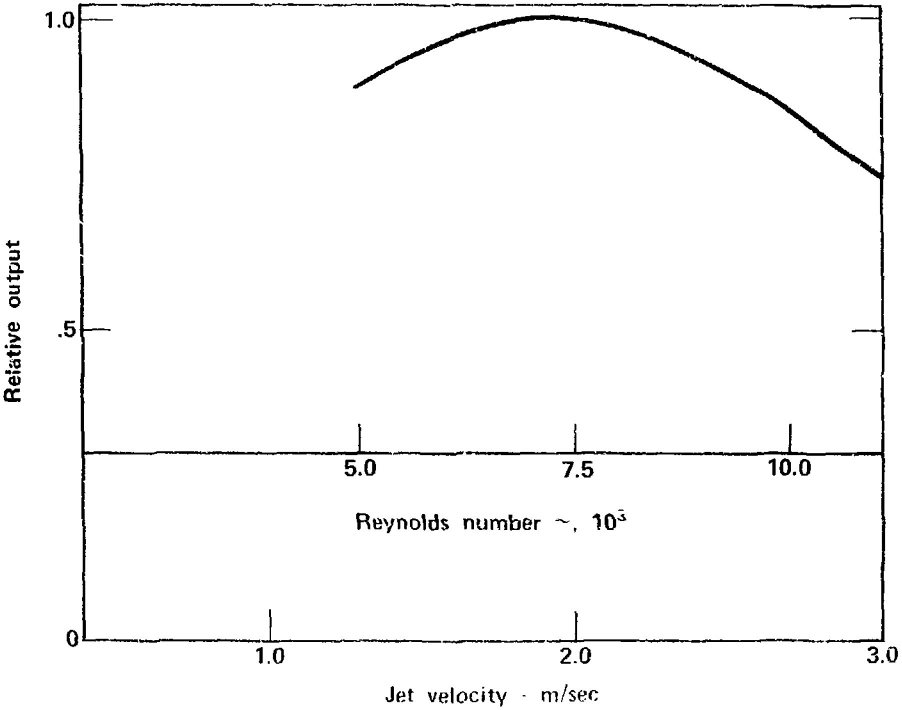


FIGURE 6

FREE JET LASER OUTPUT VS REPETITION RATE

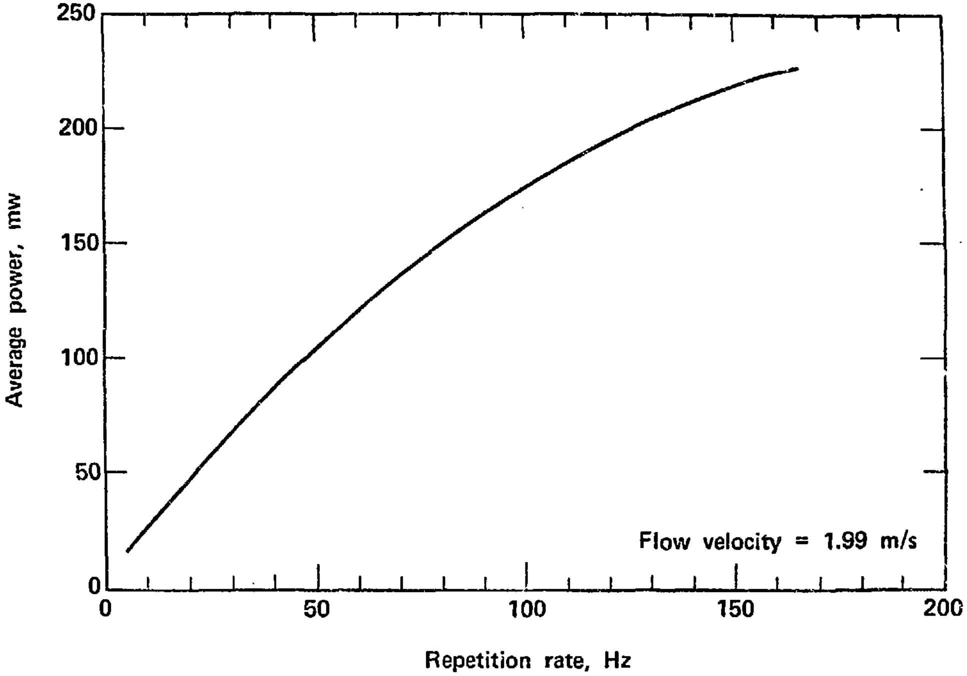


FIGURE 6

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