TUNABLE LASER FOR PLASMA DIAGNOSTICS.

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The modern laser employed for thermonuclear plasma diagnostics must provide a wide band radiation spectrum tuning, adjustment of spectrum line width, high speed tuning and precise spectrum forming. In some cases a laser capable of generating several wavelength tunable radiation lines is demanded.

With such a laser one can scan the object with discrete spectrum radiation while simultaneously analyzing several lines of reflected radiation. This makes the diagnostics process faster, easier, and less frequent tuning of the laser's spectrum is required.

We have developed a prototype utilizing a solid-state experimental Ti sapphire laser with an in-resonator radiation spectrum tuning element (fig.1).

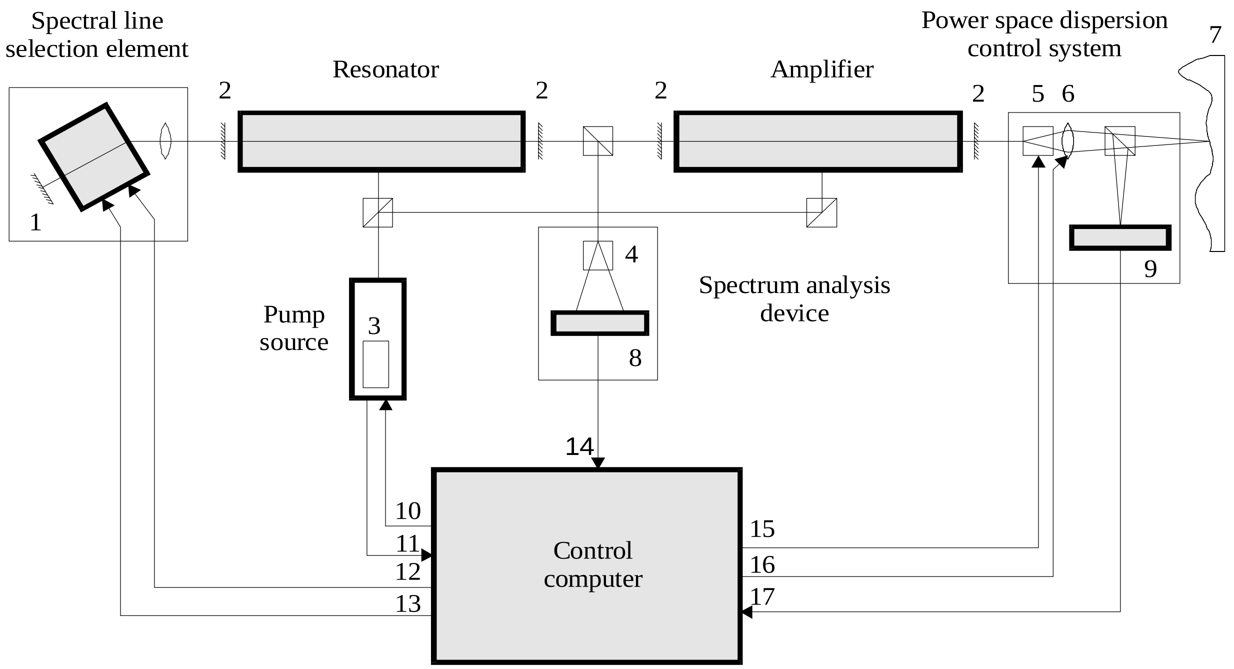

Fig.1. A simplified chart of the tunable laser prototype. 1- rear full-reflecting mirror, 2- additional full-reflecting mirror for resonator tuning with half-reflecting mirrors, 3- pump power sensor, 4- wavelength to co-ordinate convertor, 5, 6 - space modulator and collimator of the beam, 7- object illuminated by laser radiation, 8- laser radiation analysis system photosensor, 9- power space dispersion analysis system photosensor, 10- pump power control signal, 11-pump power amplifier readback signal, 12-spectrum control signal, 13- optical valve timing control signal, 14- spectral composition data, 15- beam direction control signal, 16- beam focus control signal, 17-laser power space dispersion data.

A TeO_2 opto-acoustic filter was employed as the main avelength tuning element. The laser unit consists of a gas pumping source, gas pumping power control, Z-type resonator with opto-acoustic filter, and an output radiation spectrum analysis system. The spectrum analysis system employs a Fabri-Perot interferometer, modified spectro-photometer with spectrum sensor, CCD sensors, UHF signal generators, high-frequency mixer, and amplifier. The system also includes a wintel compatible computer with video capture and UHF signal generator interfaces.

During development, the tunable laser prototype diagnostic spectrum control system and associated spectrum forming algorithms introduced most of the complexities. For spectrum forming and stabilization a device that can determine spectrum composition is required. We propose that for spectrum analysis, the Fabri-Perot interferometer with a resolution of about R $\approx 2*10^6$ can be used. The analysis of an interference image requires several stages, which are implemented by both the hardware and software of the system. The interference image is read from the CCD-sensor, transferred through the interface to the video processing board, converted to a digital form, and placed into a special memory. The software processes the image first through a static filter and second through a Fourier filter. Next the set of interference circumferences radii is determined, separately for each circumference, the set of wavelengths λ_{0i} is calculated, and the mathematical expectation of line wavelength and its dispersion are computed. The value of the mathematical expectation $M[\lambda_0]$ will be used then for determining the deviation of the current wavelength value from the set point.

The quality of a spectrum control system is determined by the control command formulation delay, and the precision of the line wavelength setting in its width and power. For the different modes of the laser (a continuous or pulse radiation modes, single- or multi-frequency modes, narrow- or wide-band modes), different laser powers, different spectral dispersion of the different types of CCDs, and different algorithms of spectrum control are demanded. Thus, it is necessary to develop a spectrum control system based on adaptive systems theory and the theory of systems with alternating structure.

We have investigated three different modes of control that could be applied to our linear CCD sensors during the laser spectrum measurements. In the first mode continuous spectrum picture scanning, the charge set resulting from the previous scan is fully removed from the sensing area of the CCD during the frame transfer. Next, the charge in the gates of the sensing area will be formed again and the process is repeated. In this mode the frame sampling frequency defines the exposure period. To change the exposure independently, and for example prevent saturation, we have utilized a second synchronous control mode. In this mode, after the scan of the frame, the rest charge continuously flows through the shift gate to accumulate in an analog register which is cleared by a periodic timing pulse (fig.2).In the third mode, intended for pulsed laser radiation, the CCD control system must start the exposure before the laser pulse. When synchronizing with the laser pulse, a signal from the laser pump lamp is required.

We propose to compute the regulator elements for CCD-sensors and opto-acoustic devices dynamically during the spectrum control process. This method is compatible with the above control system structure synthesis quality criteria and also the crystals of "flex" logic. This reduces the complexity of the control board. To develop the system synthesis algorithms we have applied graph analysis of system condition method. In each condition of the system the previously defined control tasks are executed. Optimal design of the control system also reduces a system errors and data flow between processors during parallel data processing.

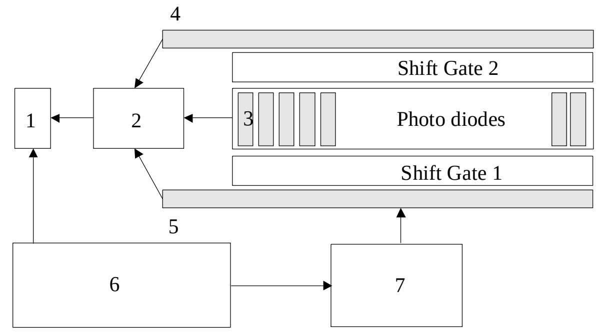

Fig.2. The internal structure of a standard linear CCD. 1- clamp amplifier, 2- shift-hold amplifier, 3- light-sensing gates, 4,5- CCD analog shift registers, 6- timing pulse generator, 7- gate driver.

Another significant problem is the processing of the measured spectral images. This challenge is quite similar to the image recognition problem in control systems where precision high sensitivity devices are used. In this task we convert the original information while selecting unique properties which accomplish a precise classification of the object.

Tests of the high-precision radiation sensor module have shown that the measured digital image in practice includes noise components that reduces its quality. This noise originates from the influence of several external factors. To reduce false information, and to improve system effectiveness, we have tried to apply colour sensors instead of black-and-white ones. Under various measurements conditions the obtained images differed. Under conditions of continuously changing external illumination, the precision of the essential interference rings radii drops. This arises from the nature of colour and from the influence of changing registration modes which leads to the loss of information. But, in the case of colour input that is varying the external illumination, this results in fewer changes in the brightness and colours of the interference picture.

Colour, as is well known, is determined by the wavelength of electromagnetic radiation. For the processing of the visible part of interference picture spectrum, a two-dimensional CCD matrix with a composite PAL-encoder was used. The signal from it was converted to digital form using an additive RGB model. A composite signal is usually used in video equipment (VHS, Video-8) that consists of intensity signal Y, colour signal U, colour signal V and several timing signals. The most common encoding method for videodata utilizes a two-dimensional matrix of intensity, with each element representing the index of a pixel colour. A doubtless merit of such a data presentation method is the possibility of efficiently updating the picture elements, as necessary, for example, when a new colour model is required. The use of a HLS model (colour tone H, intensity L and saturation S) allows application of a colour tone concept to problems of filtration, segmentation, and recognition, independent of the object illumination.

In the standard HLS model of image digitizing it is necessary to convert the former signal from YUV to RGB (that is provided by hardware), and then to convert the signal from RGB to HLS (fig. 3). The RGB to HLS transformation is executed by software.

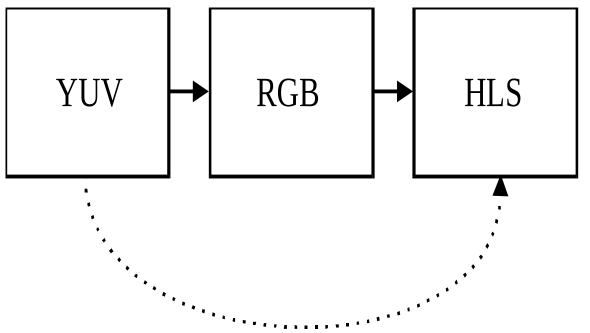

Fig.3. Data conversion sequence.

To speed up preliminary data conversion one can directly convert data from YUV to HLS (see fig.3). Digital processing in HLS form is much easier than processing of RGB signals due to their limited spectrum. However, in this prototype it is necessary to utilize an RGB-based video capture unit because a commercial YUV-HLS transforming unit hasn't been found.

Conversion from the YUV model to HLS model can be implemented at a hardware level with the following formula:

$$H = arccos(Z), \quad \text{where}$$

$$cos(Z) = \frac{0.886 \cdot V - 2.509 \cdot U}{\sqrt{6} \cdot S}$$

$$L = Y$$

$$S = (0.536 \cdot Y^2 + 1.259 \cdot U^2 + 1.038 \cdot V^2 + 0.415 \cdot YU + 0.681 \cdot YV + 0.197 \cdot UV)^{\frac{1}{2}}$$

Conversion coefficients were calculated taking into account the effective wavelength range of the laser system (from 600 nm up to 900 nm). Using the proposed scheme the influence of medium intensity illumination on system efficiency can be eliminated. This had a positive effect on the prototype when operating in a conditions of variable illumination. The reduction in the duration of preliminary image processing was strongly correlated with the magnitude of the colour image matrix.