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ABSTRACT

A microprocessor system developed at Lawrence Livermore Laboratory
has expedited the recovery of data describing the low energy X-ray
spectra radiated by laser-fusion targets. An Intel microprocessor
controls the digitization and scanning of the data stream of an X-ray-
sensitive self-scanning photodiode array incorporated in a crystal
diffraction spectrometer.

A MICROPROCESSOR SYSTEM TO RECOVER DATA
FROM A SELF-SCANNING PHOTODIODE ARRAY

By

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A microprocessor-controlled digital system was developed to recover
data from an x-ray spectrometry experiment that is a component of the
laser-fusion program at Lawrence Livermore Laboratory. The system soft-
ware was designed to allow extensive interaction between the physics ex-
perimenter and the microprocessor controller. The microprocessor has
proved to be well-suited for handling large arrays of data at a low level
of software sophistication, and its low cost and large memory capacity make
it an attractive alternative to a minicomputer-based system.

LASER-FUSION EXPERIMENTS

It is the aim of the laser-fusion program at Lawrence Livermore
Laboratory to develop the technique of inertial confinement of a controlled
thermonuclear reaction. Experiments performed by the program involve the
compression of fusion fuel targets by pulses of light from high-power solid
state lasers. The targets are glass microspheres filled with mixtures of
deuterium and tritium gases. At the CYCLOPS experimental facility a Nd/yag
laser heats the targets with 80-picosecond long pulses of one-micron light
containing 80 joules of energy. The plasma created at the target reradiates
a fraction of the energy as x-rays. The spectrum of x-rays includes the
characteristic line radiations of highly-ionized target materials such as
silicon. Theory has been developed that relates the intensities and line
profile shapes of the silicon radiation to the electron temperature and
density in the plasma. The accurate and expedient recovery of this infor-
mation is essential. We have developed a high resolution x-ray crystal
spectrometer which records silicon spectra on a spatially-resolving solid
state detector known as a self-scanning photodiode array (SSPA). The
spectrometry experiment relies on a microprocessor system to control the
digitization and processing of the array of signal levels produced by the
SSPA detector.

CRYSTAL DIFFRACTION SPECTROMETER

High resolution x-ray spectral measurements are taken commonly with single-crystal diffraction spectrographs, using photographic film to re-cord signals. An analyzing crystal will reflect with high efficiency only a narrow band of photon energies whose location in the spectrum is deter-mined by the angle of incidence of the x-ray beam on a principal crystal plane. Our instrument uses a flat crystal of potassium acid phthalate (KAP), cleaved parallel to the (010) plane. The crystal is inclined at a 14° angle with respect to the line of sight to the glass microsphere target. Divergence of radiation from the laser-heated target causes x-rays with energies in the range from 1.8 to 2.2 Kev to be analyzed by the crystal. A Reticon RL512C photodiode array located in the plane of dispersion be-hind the crystal senses the pattern of dispersed radiation.

SELF-SCANNING PHOTODIODE ARRAY

The self-scanning photodiode array is a linear ensemble of 512 PN junction photodiodes built upon a common silicon substrate. The center-to-center spacing of the photodiodes is 25 microns. A logic network of transistors is built on the detector chip to scan and multiplex the signals from the photodiodes. We have found that the photodiode array has appreciable sensitivity to x-rays with energies from 1.5 to above 10 Kev, and that the detector's response is a linear function of x-ray dose.

The signal levels from the SSPA are processed at a 100 KHz analog sample rate by a sample-and-hold circuit supplied by the Reticon Corporation. In our experiment the photodiode array is allowed to free-run without synchronization to the laser firing system. Since the photodiodes will store photocharge accumulated between consecutive scan cycles, no data is lost if the laser event occurs at an arbitrary point in a scan. The distribution of signal levels along the length of the photodiode array is reconstructed by a clock bit counter in the microprocessor system. The counter is actuated by an external event trigger.

MICROPROCESSOR SYSTEM

The serial stream of photocharge signals from the sample-and-hold
circuit is digitized with ten bit resolution immediately after a laser
shot. The central processor in our system then performs the synchronized
loading of the levels into a direct access solid-state memory. To improve
the quality of the data the CPU also does some elementary arithmetic with
the signal levels. Just prior to the laser shot, at the time that the
experiment was enabled, the CPU had scanned and stored an array of dark
current and off-set levels. These levels are subtracted from the event
data. Also, the shot data is multiplied by pre-determined factors that
account for the variation in sensitivity from one photodiode element to
another. The intensity resolution of the spectrometer data is improved
to about one part in 250 by this processing. The reduced data as well as
all segments of the raw data can be distributed to output devices, under
the control of the physics experimenter.

HARDWARE

The hardware of the data system consist of the CPU, an array of direct-
access solid state memories, and several I/O interfaces. The central
processor, an Intel 8080, incorporates an eight bit I/O data bus and a
16 bit memory bus. It can accomodate a memory as large as 64K words
in direct access and can control up to 16 I/O devices. It has an instruc-
tion cycle time of two microseconds. Our system provides 16K words of
memory, of which 6.5K are given over to software. The remaining capacity
is divided into four equal blocks to store the shot signals, the measured
dark current and off-set levels, the sensitivity factors, and the reduced data.

The existing complement of I/O devices in the system include a CRT
display, an X-Y plotter, an IRIG clock, and an ASR-33 teletypewriter fitted
with a paper tape punch and reader. The CRT display contains a 2048 word
self-scanning memory and has alpha-numeric, line graph and bar graph plotting
capability. The contents of the reduced data memory appear automatically on
this unit immediately after a laser shot. Segments of the raw data can also

be displayed, at the discretion of the system operator. The X-Y plotter
is driven by an interface that includes two 12-bit digital-to-analog con-
verters and a pen control circuit. The system software includes instruc-
tions that allow the plotter to be calibrated and scaled by the experimenter.
Permanent numeric records, suitable for loading into a general purpose com-
puter, can be generated by the teletype on punched tape. The records are
labelled with IRIG time and written in scientific notation with four decimal
digit resolution. The teletype also effects the communication of data
retrieval and outputting instructions from the experimenter to the system.

SOFTWARE

The software of the system is written in the high level PL/M compiler
language supplied by Intel. PL/M is similar to Fortran and provides the
versatility and room for expansion that our purposes require. The instruc-
tion set is contained in a programmed read-only memory (PROM) of 6.5K words.

RESULTS

The microprocessor system has processed spectrometer data on a series
of laser shots, with completely satisfactory results. The intensity reso-
lution of one part in 250 is comparable to the value that could be attributed
to the SSPA detector alone and exceeds that to be expected in recording spectra
on photographic film. The immediacy with which the data is presented has
proved to be of benefit to the laser-fusion program.