FIBEROPTICS-BASED INSTRUMENTATION FOR STORAGE RING BEAM DIAGNOSTICS*

J.M. Byrd, S. De Santis# LBNL, Berkeley, U.S.A.
Y. Yin, YYLabs, Fremont, CA 94537, U.S.A.

Abstract

In several cases, coupling synchrotron light into optical fibers can substantially facilitate the use of beam diagnostic instrumentation that measures longitudinal beam properties by detecting synchrotron radiation. It has been discussed in [1] with some detail, how fiberoptics can bring the light at relatively large distances from the accelerator, where a variety of devices can be used to measure beam properties and parameters. Light carried on a fiber can be easily switched between instruments so that each one of them has 100% of the photons available, rather than just a fraction, when simultaneous measurements are not indispensable. From a more general point of view, once synchrotron light is coupled into the fiber, the vast array of techniques and optoelectronic devices, developed by the telecommunication industry becomes available.

In this paper we present the results of our experiments at the Advanced Light Source, where we tried to assess the challenges and limitations of the coupling process and determine what level of efficiency one can typically expect to achieve.

INTRODUCTION

The main challenges in realizing a beam diagnostic system that makes use of synchrotron light carried on optical fibers are to be found in the coupling efficiency and in the dispersion introduced by propagation along the fiber. These two aspects are indeed strictly correlated when one is trying to design such a system: since there are minimum requirements on the signal-to-noise ratio, if the coupling efficiency is too low, one is forced to couple light on a larger bandwidth, which in turn makes the dispersion worse, for example.

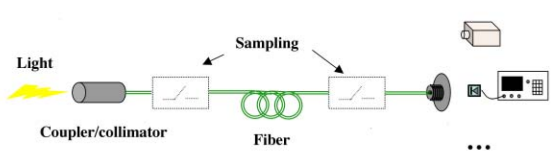

Figure 1. Scheme of principle of a fiberoptics-based system. A light sampling component can be present at the beginning of the fiber, after some distance, or not at all.

Figure 1 shows the typical elements a generic fiberoptics-based diagnostic system is composed of. Their choice depends of course on the characteristics (i.e. photon flux) of the synchrotron light source and on specific applications one may have in mind. Commercially available optical fiber can support transmission with low attenuation in a wide wavelength region from ~1600 nm to the visible spectrum. In practical applications one would have to transmit synchrotron light over distances of a few 100's of meters at most, so that fiber propagation attenuation is seldom an issue. In case of highly radioactive environments, radiation-hard fibers, usually Fluorine based, are available at the price of a slightly higher attenuation [2].

While for our applications optical fibers are inherently wide-band, as just said, other components one has to use (couplers, detectors, etc.) work instead on limited wavelength ranges. Commercially, three bands have seen the almost totality of technological developments and are readily available: 1550, 1310 and 850 nm.

A first choice the designer has to make is between single-mode and multimode fibers. This is another case where one has to find a compromise between coupling efficiency and dispersion:

- Multimode fibers allow for a substantially more efficient coupling into the fiber, up to a large fraction of the total available power. On the other end, they are dominated by intermodal dispersion. Fig.2a shows the classic bandwidth/distance curves for multimode fibers. Commercial graded-index fibers developed for LAN's can provide bandwidths around 30 GHz, for a 100 m long fiber, in the 850 nm range [3].
- Dispersion in single-mode fibers can in principle be cancelled out by using *dispersion compensated fibers*, even in the case of a wideband source. Fig. 2b shows the dispersion curves for several types of fibers. It can be seen that it is possible to obtain near-zero dispersion, if the bandwidth is kept small enough, once again underscoring the importance of obtaining the best possible coupling of synchrotron light into the fiber.

In general, best coupling is obtained through the use of telescopes, GRIN lenses, or collimators, depending on the specific characteristics of the light port and the source. It must be kept in mind that, in most cases, the source's modal spectrum cannot be transversally matched into a single-mode fiber propagating mode, so that the coupling efficiency is necessarily much lower than unity.

Another way of canceling the effects of dispersion, for both single and multimode fibers, is outlined in Fig.1: by sampling the signal immediately after the coupling elements. the effect of the fiber is taken out of the

*Work supported by the.U.S. Department of Energy under. Contract No. DE-AC0-05CH11231.
#sdesantis@lbl.gov

equation since each sample can be time-tagged and the time resolution is defined by the samples duration alone.

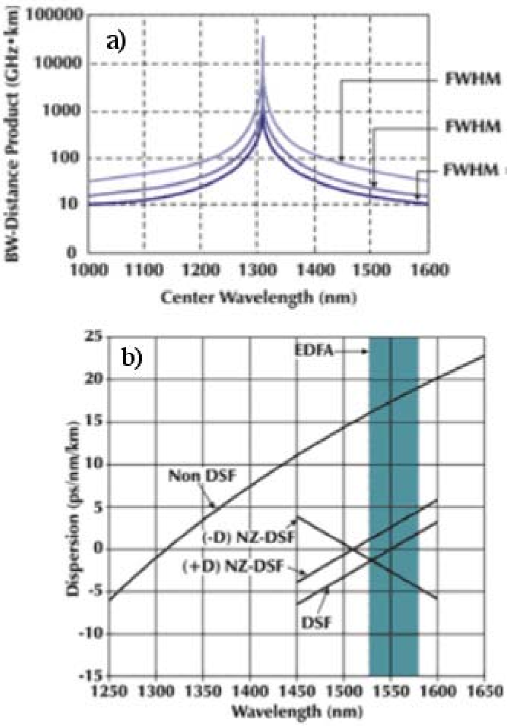

Figure 2 Bandwidth/distance curves for multimode fibers (a). Dispersion curves for single-mode fibers (b).

EXPERIMENTAL SETUP AT THE ALS

We performed experiment at the ALS, where a diagnostic beamline is available from time to time, using a variety of fibers, couplers and detectors.

Beamline 3.1 synchrotron radiation source is one of the ALS 1.3 T dipoles. The beamline, which is dedicated to an x-ray CCD camera during user operations, can be used for visible-IR wavelengths during dedicated shifts.

Figure 3 shows the photon flux out of an ALS dipole with 400 mA circulating in the machine.

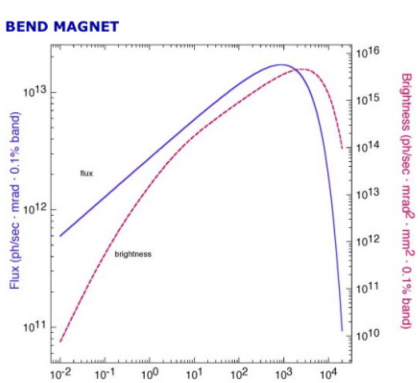

Figure 3. Photon flux for an ALS dipole.

The beamline optics have been described in [1].

Figure 4 shows our experimental setup, with the final three flat mirrors and the micrometric positioning stage with the telescope used with multimode fibers.

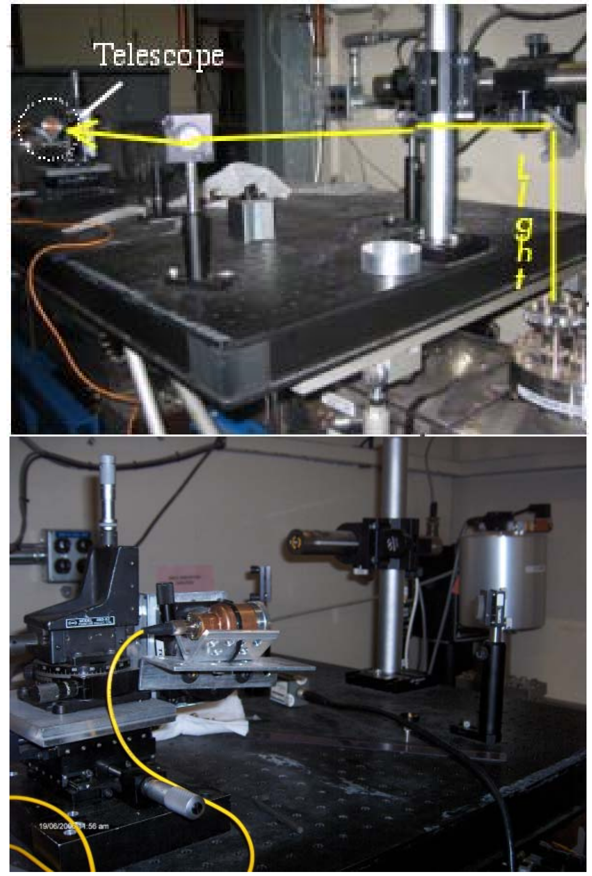

Figure 4. Experimental setup at Beamline 3.1, with coupling stage detail.

We use the visible component for a first order alignment and then we optimize coupling by maximizing the readout on an optical powermeter at the desired wavelength. The average available power at maximum current can be calculated from Fig.3 and in the 1000-1600 nm band is found to be around 110 μW. One has to take into account losses on the mirrors: we measured the losses on the three external mirrors and found them to be around 3 dB. There is another in-vacuum mirror and the two K-B mirrors that focus the synchrotron radiation. At this point we don't have a definite value for the losses introduced by these mirrors, but we guess we could have only a quarter of the theoretical power available at the coupling element.

For single-mode fibers we tried a variety of arrangements and finally we got our best results using a Thorlabs Long Working Distance Collimator, which has a 10% bandwidth around 1550 nm.

For signal detection we used several different photodiodes (Si and InGaAs) and a LeCroy 3 GHz oscilloscope, as well as an 86116A optical input module on a 53 GHz Agilent sampling scope. We eventually obtained our best results using a Discovery Semiconductors DSC50S InGaAs PIN diode [4], which is limited to a 5 GHz band though.

EXPERIMENTAL RESULTS

At present we have concentrated our efforts on obtaining maximum coupling of synchrotron radiation into the optical fiber on a 10-20% band at either 1550 or 1310 nm, where we have most of our components available. Once one has achieved coupling a healthy signal into the fiber, then it is relatively easy to use longer fibers and study the effects of dispersion.

As coupling of average power is concerned, we have obtained up to 10 μW on multimode fibers. Based on what said in the previous section about the total available power, that means at least 20%, and up to 50% coupling efficiency. For single-mode fibers the result is substantially lower: not only is more difficult to deal with a 9 μm, rather than a 50 μm, core experimentally, but considering our source characteristic one cannot expect to mode match more than a few percent into the single-mode fiber [5]. In fact, we have obtained values 10 times lower with single-mode fiber, compared to multimode.

Nonetheless even this lower coupled power is sufficient to give a rather accurate longitudinal profile of the ALS beam.

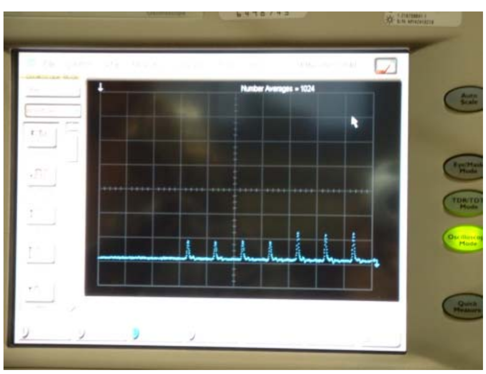

Figure 5 Beginning of the ALS bunch train (Corning SMF-28 fiber, Thorlabs collimator, Discovery Semiconductors PIN diode).

Figure 5 shows the screen of our Agilent 53 GHz digital sampling scope. We used a single-mode fiber, with the Thorlabs collimator and the DSC50S photodetector described above. The first 7 ALS bunches, following the ion-clearing gap in the fill are clearly visible, spaced by 2 ns.

Figure 6 (top) shows the postprocessed numerical data of a similar picture: this time the horizontal span is increased so that we see the first 14 bunches, the large bunch in the middle of the gap (a.k.a. *camshaft*) and, in between them, a small bunch generated by the injection process (*parasitic*, these are eliminated for user operations by a betatron resonant cleaning procedure). Fig.6. (bottom) shows a close-up of the camshaft. The measured FWHM is around 100 ps, which is higher than the expected ~60 ps. In this case (we where using just a few feet of fiber) this is not due to dispersion, but to the response time of our detector. Also, there is a 20 ps jitter in the storage ring orbit clock used for timing, which also contributes to the bunch widening, when using a sampling scope.

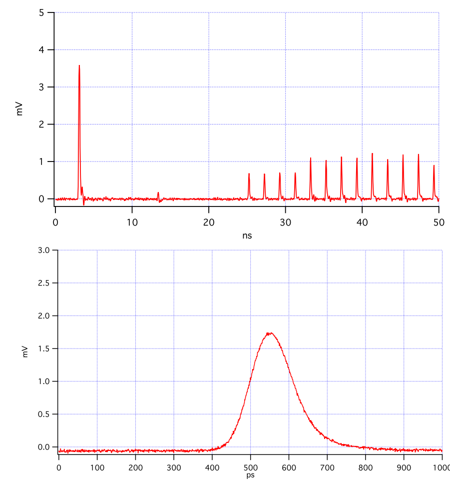

Figure 6. Postprocessed data. ALS train, camshaft bunch and parasitic bunch (top), detail of camshaft (bottom).

CONCLUSIONS AND FUTURE PLANS

Our experiments have shown that it is possible to obtain adequate coupling efficiency at the ALS using both multimode (~50%) and single-mode (~4%) fibers. Comparing with the available photon fluxes and most required measurements on other machines (LHC, for instance), we believe these are fairly representative results.

We are planning to further the investigation, as dispersion is concerned, after buying longer fiber spools and a new photodetector with a 10 ps response time, which we have already identified on the market.

ACKNOWLEDGMENTS

The authors wish to thank the ALS personnel who helped with the scheduling of the measurements and in setting up the machine.

REFERENCES

[1] S. De Santis, J.M. Byrd, *et al.*, "Fiberoptics-based Instrumentation for Storage Ring Longitudinal Diagnostics", EPAC'06, Edinburgh, June 2006, p. 1247.
[2] http;//www.thorlabs.com
[3] LaserWave 500™, http;//www.ofsoptics.com
[4] http;//www.chipsat.com
[5] M. Zolotorev, private communication.