<u>List of questions & answers for Structured Laser Beam (SLB) technology.</u>

1. **Is this approach based on an axicon lens?**

No, it is not based on an axicon. The technology is an optical system and method for generating a structured beam. The patent application is not yet published; therefore, we cannot share further information about the optical system itself, except under NDA. We have an NDA template that we can provide.

2. **Based on our understanding so far, our conclusion is that this is a Bessel beam technology. Can you confirm?**

Yes, the technology creates an approximation of a Bessel-like beam. True Bessel-beams are not possible to achieve in practice. It is therefore preferable to call it a Structured Beam. For the SLB, the structure is a little different from the one of Bessel-like beams obtained with axicons, and the structure can be tuned. Furthermore, the axicon can only provide a finite beam over relatively short distances, whereas the SLB is effective over much longer distances.

3. **Is it multispectral? Is it possible to adjust the wavelength? How do you adjust it?**

Yes, the system is tunable. The SLB can be produced for any wavelength and potentially for any power. It depends on the input source you choose to use, and the exact components of the system. We can illuminate the SLB generator using different wavelengths, or white light.

4. **Can polarized light be used with the system?**

Yes, a polarized beam can be used, and polarization can vary the properties of structured beams in some cases.

5. **What is the relationship between distance and beam spreading?**

The Structured Laser Beam (SLB) outer ring diameter and central spot diameter increase linearly with distance. The diameter of rings depends on wavelength.

6. **Would the rings be of any value?**

The number of rings and the diameter can vary, which may be of use in some applications (to be explored). However, the intensity of the very large rings will likely be on the edge of detection sensitivity.

7. **How is energy output affected by SLB?**

Total energy is conserved, but the measured energy output would depend directly on the configuration & inputs of the system – including the power, wavelength, etc. There are numerous different outcomes that would need to be simulated and tested experimentally.

8. **Does it waste energy in any sense? Do the rings "take" energy?**

To our knowledge, there is no additional loss of energy compared to a Gaussian beam – although further experimental tests would need to be conducted to confirm energy distribution - intensity. In the case of the SLB, the system can be configured so that the energy is more concentrated in the central spot, or it can be configured so that more of the energy is in the outer rings. Like a Gaussian beam, energy will spread over distance.

9. **Is there a critical distance at which the SLB has higher intensity than a normal Gaussian beam?**

Energy output would depend directly on the system configuration; therefore, such a 'critical distance' will vary in each case.

10. **How does the spot size relate to energy-delivery and behavior?**

The spot size is dependent on the set-up and wavelength, not on energy.

11. **Why does the intensity observed decrease with the square of the distance from the source? Is this different from the current alternative technologies for creating Bessel beams?**

Based on preliminary tests, the intensity is observed to decrease with the square of the distance from the source – which is a similar effect as in the case of Gaussian beams. The wave front is similar to the classical spherical or parabolic wave front, only intensity distribution differs from a Gaussian beam, so the intensity roughly decreases with distance in far field. It is similar to an axicon-created beam in near field.

In the case of the SLB, the energy is spreading in space in a kind of solid angle, and part of it remains useful for the SLB creation. The SLB will propagate over very long distances – theoretically infinity. In the case of a Bessel Beam created with an Axicon, the energy is spreading in a different way. One could imagine energy spread on the surface of a cone. The Bessel Beam is created only in the top of this "cone" on a finite and relatively short distance.

12. **It sounds like this technology has an efficiency problem. How does it compare to competing Bessel beam technologies? Is it feasible to use in material processing if efficiency to central spot is this low? Or is it much better at short distances?**

The SLB system can be tuned to generate a higher intensity central spot at near or far field. Today, deep-hole material processing is mainly used for transparent material. Non-transparent material would block the rest of the SLB, so it cannot be generated at depth.

13. **What is the power transfer between the laser and the output of the manipulator?**

Depending on the generator setup, almost 100% of the power at the input could be retrieved at the output. It is very much dependent on the generator design.

14. Can we tune your beam so that there is less power in the outer rings, so that we do not have burn marks?

We can easily tune the SLB to generate an intensive central spot and a large number of low intensity rings with very small intensities in comparison with axicon-generated Bessel beams.

15. How does partial blocking affect energy delivered at the target?

Logically, there will be some loss of energy after partial blocking of the beam, however, based on the physics of the beam, we expect that this relative loss will be less than would occur with a Gaussian laser. This assumption needs to be experimentally tested.

16. In rain/snow/fog etc., how is the measure of photons affected?

The SLB was tested in rain/snow conditions and temporal distortion of part of the beam was observed, but the time-average image (for 1 s or more) seemed to be stable. The behavior of the SLB in fog is expected to be similar to Gaussian beams of the same wavelength.

17. How sensitive is the system to vibrations?

It seems to be quite robust, but requires further testing.

18. Does the manipulator use refractive elements? Or reflective?

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19. What are the reflection properties of the SLB? Does it reflect light in the same way as a Gaussian beam? Is more or less light reflected back from the target back to the source?

The reflection properties are similar to the Gaussian beam. If you partially block the SLB, then only part of beam is reflected. The shape and position of the beam might also change.

20. Can the reflection of the rings be used for any type of analysis?

Yes, for analyses of shape and deformation of reflective surface, for example, or for estimation of position of refractive mirror, etc.

21. In our literature review, we have found limited applications of Bessel beam technology in metrology. How do you envision the application for this technology in metrology? What advantages does this technology bring to your metrology applications?

We see advantages of the technology in large-scale metrology & alignment because the beam maintains its small & bright central spot, even at long distances. At shorter distances, it is less likely that the beam has advantages. However, it would need to be tested and compared with other solutions because we have not used the beam for smaller-scale metrology.

22. How does your metrology system work? What is its purpose?

One of the aspects of the large-scale metrology at CERN is the measurement, the control and the monitoring of accelerator elements over long distances, up to 200m. The requested precision varies from 0.1mm up to some microns in the most demanding cases. For the time being, the most precise systems are based on measurement of offsets to a reference line or surface. The sensors are capacitive sensors and the references are achieved with stretched wires in the case of WPS (Wire Positioning System) or a water surface for the HLS (Hydrostatic Leveling System). The use of wires or water for such precision generates many constraints i.e. wire tensioning, sag modeling, atmospheric pressure effects, earth tide effects. These are not always easy to solve. A laser-based system therefore provides an advantage vs existing solutions.

23. Based on our literature research and your technology brief, the 3 unique advantages of the technology are: 1) the alignment is less critical; 2) the depth of focus is longer; 3) it is cheaper than current solutions. Is that correct? Are there any other?

The key advantage of the technology is the long-distance, sharp focus of the beam due to the small & bright central spot that can be achieved. There are other advantages associated with the technology (as listed on the technology brief), but the importance of these advantages depends on the application.

24. How small can it be made? How is the function affected by size?

The prototype built at CERN for large-scale metrology is roughly 20cm x 5cm in size. In theory, the system could be made much smaller or bigger than this. E.g., you can generate ten times bigger SLB diameters with a ten times bigger generator (roughly) in useful range. Through NDA, we can share further details about how the system works, which would enable you to explore the lower and upper size limits.

25. What is your estimation of how ready the technology is now? How much more development is needed for industrial applications?

For geodetic metrology, we have a prototype built and we are in the process of validating it in the lab (TRL 3 - 4).

For other applications, it has not been tested, so we are closer to TRL 1 – 2.

26. How complex is it to manufacture for different purposes and sizes?

It would depend on the application. However, we expect that the system would not be significantly more complex than existing solutions using Gaussian beams.

27. What is needed to manufacture the system?

This is related to the patent, which is not yet published. The information can only be shared under NDA. We have an NDA template that we can provide.

28. **Do you have any knowledge within LiDAR systems, and how the technology can be used/integrated into such systems?**

We have not yet tested the technology in this application domain, therefore, we do not have this information, but we expect that it can be integrated to LIDAR system without problem.

29. **What are the limitations of your technology compared to what is reported in the literature for Gaussian beams, and similar Bessel beam technology?**

The main drawback compared to Gaussian beams is that the energy is spread-out more (e.g., the outer rings have a wide diameter). However, the benefit of the system is that it can be tuned so that a significant amount of this “useful” energy is more concentrated to the central spot, or in the rings, depending on the application.

Based on our current experience using the SLB, we see no disadvantage compared to state-of-art classical Bessel beam technology.

In each case, the cost of replacing existing solutions with an SLB solution would need to be calculated - and this would depend on the configuration used.

The limitations would mainly depend on what you want to do with the beam.