4. Conclusions

The Advanced LIGO PSL delivered an ultra-stable, high-power laser beam. Meeting the stringent design requirements of Advanced LIGO required elaborate active and passive stabilization schemes which reduced the laser noise by several orders of magnitude. With the comprehensive characterization of two PSLs, the reference system and the first observatory system, we were able to show that most design requirements for Advanced LIGO were fulfilled. Only the first-loop power stabilization at low frequencies showed excess noise not reaching its goal; this is not critical for the Advanced LIGO project, because the second power stabilization loop will be responsible for the ultimate power stability. The typical output power of 140 W of the reference system was about 15% lower than the goal of 165 W. However, the first observatory system had an output power of 157 W after installation. No long-term average value is available yet. Furthermore, although the in-loop measured frequency stability was consistent with the design requirements, an out-of-loop measurement would be necessary to state that the frequency noise design requirements were met. Such an out-of-loop measurement will be performed using the input mode-cleaner in the future. Since the frequency stabilization concept is very similar to Initial LIGO and key hardware components are reused, we expect to reach the same stability as in Initial LIGO which would fulfill the frequency noise requirements for Advanced LIGO.

The measurement and analysis of possible cross couplings between different control loops showed no critical coupling affecting control loop stability or noise performance. Some coupling factors were larger than expected and might need further investigation.

The computer system monitored the state of the PSL and performed fast and automatic lock acquisitions. Thus we were able to reliably and continuously operate the PSL in a 24h mode. Interruptions were necessary only due to a few failures caused by experiments during installation and optimization, due to power outages, or due to regular short maintenance intervals.

Many stabilization schemes employed in the PSL can be easily adapted to other continuous-wave single-frequency laser systems. Thus various other high-precision optical experiments can use these techniques to reduce laser noise which might limit their sensitivity.

The PSL is a crucial subsystem of Advanced LIGO, and most other subsystems rely on the PSL. Thus it plays an important role in the success of the Advanced LIGO detector which is expected to detect gravitational waves on a regular basis in the near future.

Acknowledgment

This research is supported by the Deutsche Forschungsgemeinschaft as a part of the QUEST cluster of excellence and the German Volkswagen Stiftung. LIGO was constructed by the California Institute of Technology and the Massachusetts Institute of Technology with funding from the National Science Foundation and operates under cooperative agreement PHY-0823459.