

## CHAPTER V

### CONCLUSION AND SUGGESTIONS

#### 5.1 Conclusion

Based on the research results, which include the measurement process, data processing, and analysis of the LINAC output characteristics for photon and electron beams, the conclusions of this research are as follows:

1. Measurements of the photon beam show that the With Flattening Filter (WFF) mode produces the smallest and most stable deviation, which is around  $\pm 0.2 - 1\%$ . This indicates a more even dose profile due to the use of a flattening filter. In contrast, the Flattening Filter Free (FFF) mode shows a larger deviation reaching  $\pm 3 - 4.7\%$ . However, after the adjustment process, the deviation decreases to  $\pm 0.01\%$ . Thus, both modes still meet clinical needs, although the WFF mode shows superior consistency.
2. Electron beam measurements show that the deviation obtained varies depending on the energy used. At 6 MeV, the highest deviation is between  $-3.5\%$  to  $-1\%$ . 9 MeV shows a relatively small deviation of around  $-0.5 - 0\%$ , while 12 MeV is in the range of up  $-2\%$  to  $0.5\%$ . 16 MeV has a deviation of  $-3\%$  to  $-0.1\%$ , while 18 MeV shows a deviation of around  $-0.07\%$  to  $0.5\%$ . This indicates that electrons with energies of 9 MeV and 12 MeV have the best stability compared to other energies.
3. The results of the study show that the With Flattening Filter (WFF) mode is fully within the tolerance limit  $\pm 2\%$  according to the international standard IAEA TRS-398. In the Flattening Filter Free (FFF) mode, there are several deviation values that exceed the tolerance limit, but after adjusting the deviation, they are back within the permissible range. For electron beam of 9 MeV and 12 MeV energies, they meet the tolerance limit, while energies of 6 MeV, 16 MeV, and 18 MeV show some values that exceed the tolerance limit  $\pm 2\%$ . Overall, these deviations are still acceptable because they are influenced by the physical characteristics of each energy.
4. Stability tests show that the LINAC output on the photon and electron beams IS in a stable condition. In the photon beam mode, With Flattening Filter ( $R^2 =$

0.3333) and Flattening Filter Free ( $R^2 = 0.5000$ ) mode, show very small changes in charge between measurements, so that low values  $R^2$  do not indicate instability, but are due to too small data variance. In the electron beam, all energy levels have good stability. The 9 MeV energy has the most regular pattern ( $R^2 = 0.8000$ ), while the other energies, 6 MeV, 12 MeV, 16 MeV, and 18 MeV, show low  $R^2$  values due to very minimal charge fluctuations. Thus, although the  $R^2$  values vary, all photon and electron beams are considered clinically stable because the charge output remains consistent in each repetition.

5. Statistical testing confirms that there are significant differences between WFF and FFF photon modes at all tested bias voltages (+400 V, -400 V, and +100 V), as indicated by p-values  $< 0.02$  and calculated t-values far exceeding the critical t-values. Although the difference is statistically significant, it represents the inherent physical characteristics of each beam mode and does not indicate instability in the LINAC system. Furthermore, the Two-Factor ANOVA results for electron beams demonstrate that both energy and voltage variations significantly affect the measured charge values ( $p < 0.02$ ), while no significant interaction is observed between energy and voltage ( $p > 0.02$ ). The extremely small within-group variance confirms high repeatability and measurement reliability. Statistical analysis was used as supporting data, while the most representative modes in sequence were WFF, FFF, and electron beam. The statistical results show significance, but all modes are still within the tolerance limits and not clinically significant.

## 5.2 Suggestions

1. For Universitas Pembangunan Nasional “Veteran” Jawa Timur, further research can be directed at expanding the study of dosimetric uncertainty, comparative evaluation of international calibration protocols such as IAEA TRS-398, AAPM TG-51, and TRS-483, and the use of Monte Carlo-based simulation methods to model dose distribution in various clinical settings. The results of this research can also be integrated into the practicum activities of the Medical Physics major so that students can gain direct experience related to the calibration process and stability evaluation of LINACs.

2. For BPAFK Surabaya, this research is expected to be a consideration in improving operational standards related to dosimetry quality control (QC) and quality assurance (QA). It is also recommended that BPAFK Surabaya conduct periodic verification using a variety of measurement methods and equipment to ensure uniform calibration across all radiotherapy installations.
3. For Hospital X in East Java, further research could focus on monitoring LINAC stability over a longer period of several months, as well as examining environmental factors such as temperature, humidity, and frequency of use that may affect LINAC output stability. The hospital is also encouraged to strengthen its daily QA program and routinely conduct internal dose audits to ensure the accuracy of radiation therapy safety funds.
4. Future research is recommended to involve a wider variety of measurement parameters, including the use of different field sizes, changes in Source to Surface Distance (SSD), depth, energy, and beam mode. This will allow for a more comprehensive characterization of the LINAC output stability of both photon and electron beams.