Downtime and Stability Evaluation of Mechanical Parts for Cobalt-60 Radiotherapy Units According to Standard Recommendation at NCI - U of G

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https://sriopenjournals.com/index.php/engineering_technology_review/index

Citation: Zobly, S. & Reichenvater, H. (2021). Downtime and Stability Evaluation of Mechanical Parts for Cobalt-60 Radiotherapy Units According to Standard Recommendation at NCI - U of G, *Engineering & Technology Review*, 2(1), 14-22.

Research Article

Abstract

Cobalt radiotherapy is an external beam radiation therapy used to treat primarily bone cancer and tumors of the breast, head, and neck. Most cancer patients need radiation therapy during their curative and palliative treatment to cure or control the disease while minimizing complications to healthy tissues. In developing countries, cobalt radiotherapy machines are the most cost effective and relevant methods of cancer treatment and cancer control. However, there is an acute shortage of radiotherapy facilities in a number of countries such as Sudan. Keeping the existing facilities functioning within the standard requirements is extremely challenging due to the shortage of spare parts, lack of quality control tools, and complications with calibrating the quality control tools, in addition to the availability of instrumentation of a low quality. The mechanical performance of two cobalt radiotherapy machines was assessed over a span of twelve months to evaluate stability, downtime, and performance. The results show the instabilities of the performance of mechanical machine parts, prolonged downtimes, and increased frequency of breakdowns of the two teletherapy machines considered in this paper. The aim was to ameliorate the availability and reliability of the equipment thus guaranteeing higher performance and reduced problems in clinical service. After the input power supply system was modified, a marked improvement in the availability of the machines was experienced. In addition, it was decided that gantry and collimator checks have to be performed routinely. Complete machine interlock tests take place daily in the morning before clinical service commences and during the day, two biomedical engineers must be in attendance as long as clinical treatment is taking place. Although these measures lead to a reduction in the number of patients treated, the improved reliability and availability of the machines make more than up for the difference

Keywords: Downtime, Cobalt radiotherapy, external beam, cancer, quality control, breakdown.

1. Introduction

In Sudan, there were about 33,000 cancer patients registered in 2013, and this number increased as time passes. There are about 25,746 new cancer cases detected in 2018, and over 50% of these patients die because of this disease (17,160) [1]. To control and cure cancer patients, radiotherapy centers are essential because most of the patients need the application of radiation during the course of their treatment [2]. Only three government radiotherapy centers are presently operational, excluding the two new future centers where clinical service has not yet commenced (Universal and Marawi Centre). The center established in the north of Sudan (Shendi) is not yet operational due to some logistical and management problems. The second one is located in central Sudan in Wad Medani and is receiving patients from all over the country and from countries in the region. This center is equipped with two cobalt-60 machines and one linear accelerator. Sadly, in this center, the linear accelerator is down and treatment of patients can only be done with Co-60 units. The third center (RICK) which is located in the capital city is equipped with four Co-60 machines and two linear accelerators. Unfortunately, only three cobalt-60 machines are in clinical operation at only 40% of their maximum capacity. Both linear accelerator plants are out of order.

Co-60 machines are the essential workhorses needed in cancer centers in developing countries. The numbers of cobalt machines available in Sudan including non-functioning machines are at the moment seven units. According to WHO recommendation, a developing country should have at least one teletherapy unit for a population of one million [3]. Applying this rule of thumb, Sudan would need to increase the number of machines to more than forty machines. Some of the existing machines are old, outdated, or obsolete that would further increase the local requirements for teletherapy machines. As the population in Sudan is expected to increase within the coming years; the number of new cancer patients will increase accordingly. Thus building new radiotherapy centers and increasing the number of radiotherapy machines is essential. In addition, proper maintenance and care are needed to keep older machines in perfect condition.

It is very important to keep radiotherapy machines within their specified performance to minimize the dose to patients outside the target volume. This is achieved by implementing a good quality control program for the machines. Quality control as defined by WHO is the very basis for qualitatively and quantitatively correct treatment of patients [4] provided the stability of the machines allow a performance according to the acceptable tolerances. The accuracy of a Co-60 machine should be checked carefully, since any error incurred may result in ineffective or dangerous treatments. These checks are time-consuming and require the full commitment of the entire staff, thus a team effort with responsibilities of the various tasks divided among physicists, dosimetrists, therapists, and biomedical engineers.

The quality performance of radiotherapy machines is an ongoing evaluation of functional performance characteristics. These characteristics will eventually influence the geometrical and dosimetric accuracy of the applied dose to the patients. The performance of radiotherapy equipment can change suddenly due to electronic malfunction, component failure, or mechanical breakdown, or can change slowly alter due to deterioration and aging of components [5]. Therefore, quality assurance measurements should be performed periodically on the machines, as should be on the monitoring equipment. Periodic maintenance inspections (PMI) and preventive maintenance (PM) will ensure the correct performance of both the treatment machines and their QA- and QC-instrumentation. The goal of these procedures is to assure that the performance characteristics of the equipment, demonstrate no serious deviations [6, 7]. Quality control tests shall be performed daily, weekly, and so on. The tolerance value for each parameter should be specified by the manufacturer. Many authors and reports describe how to perform the quality control and quality assurance of the radiotherapy systems [8 - 15].

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Daily weekly and monthly tests were considered in this study but, a comprehensive dosimetry test, which is done annually wasn't considered in this paper. The tests included in this work address the problems and effects on patients when doses delivered are outside the target areas due to irregular table motion, unwanted gantry and collimator shifts, incorrect field size alignment, incorrectly adjusted lasers, emergency safety interlock problems, and also take cognizance of machine breakdown times.

2. Material and Methods

To measure and record the mechanical accuracies in Co-60 radiotherapy machines there are some essential tasks performed before and during cancer patient treatments. The machine quality control results have to be according to international standards and the specifications provided by the manufacturer of the teletherapy machine. The quality control of radiotherapy equipment is an ongoing evaluation of functional performance characteristics. Such tests on the cobalt machines are performed daily, monthly, and annually. The tolerance values for geometrical and mechanical parameters were adopted from AAPM report No. 13 [6] and the manufacturer's technical specifications.

The study of the stability of the radiotherapy Co-60 machines conducted for twelve months at the radiotherapy cancer center, using two Co-60 machines manufactured by UJP PRAHA Company (TERABALT Radiotherapy Unit Type 100) with a half-life of the source of about five years, the maximum activity of the source was 392 (TBq). ETOPOO digital and water spirit levels, waterproof 225 mm protractor, 360° indicator were used to measure the angles of the gantry and the collimator. The cobalt machine used to perform this work is shown in figure 1 below.

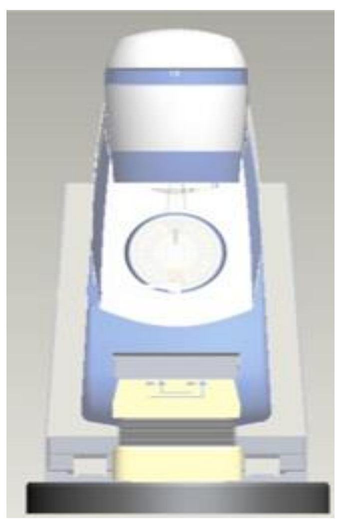

Figure 1. TERABALT 100

For field size and isocenter checks with different gantry angles and the SSD indicator, a field size checker was used. Figure 2 shows the field size checker used to perform this work.

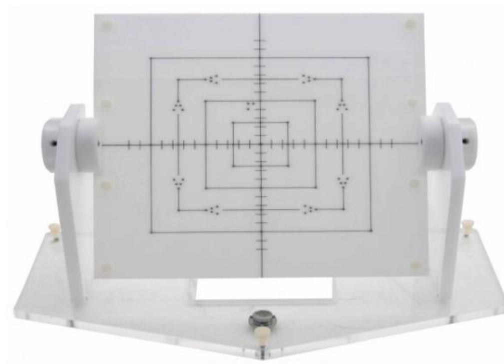

Figure 2. Field size checker

Checks to be undertaken daily are:

- Field size accuracy
- Gantry and collimator angles
- Gantry isocenter
- Couch lateral and longitudinal stability and couch isocenter
- Optical SSD indicator
- Light / radiation field alignment

The tolerance and the acceptable limit for the gantry and collimator angles was ± 0.5º, the optical distance indicator limit was ± 2 mm, the limit for treatment couch was ± 2 mm, the isocenter limit ± 1 mm, the limit for the optical distance was ± 1 mm, and the acceptable limit for the field size and edge was ± 2 mm [16]. Data from this study were analyzed and compared with international standards in addition to the manufacturer's specifications.

3. Result and Discussion

The actual time the two machines were available for treatment was calculated. Our Co-60 units have to be available for clinical operation for approximately 9 hours per working day for 5 days per week, resulting in around 180 hours per month or 1080 hours per six months period. The experienced downtime due to breakdowns for one unit was 225 hours during this semi-annual time span which represents 20,8% down time versus 79,2% availability.

This performance is unacceptable when compared with international standards and actions were therefore needed. The downtime was calculated in the following fashion:

$$\text{Breakdown time} = \left({}^{225}/_{1080}\right) * 100 = 20.8\,\% \quad (1)$$

$$\text{Availability time} = 100 - 20.8 = 79.2\,\%$$

Once the power supply to the machines was modified in order to provide a stable voltage which suppresses voltage spikes that may usually harm the electronics circuits, an improved quality control system and the stand-by of two biometric engineers, the downtimes due to failures of the equipment decreased within the following six months to 36 hours only. This relates to a downtime percentage of 3,3% and availability of the machines of 96,7%. Comparing these two semi-annual measurements, the performance and availability of our Co-60 units, have greatly improved and are now on an acceptable level.

It was also discovered that the patient table's position in the longitudinal plane produced an error of 0,3 mm and despite attempts by us and the manufacturer's agent in Sudan, this inaccuracy could not be greatly reduced. According to the engineer of the manufacturer's agent, it would cost approximately 20 to 25% of the price of a new machine to rectify this inaccuracy. However, after having carried out some modifications, the error was successfully reduced to 0,2 mm which is within the acceptable tolerance according to AAPM Report No 46 [17]. No adjustment was necessary to field light, lasers, and range finder (ODI). The couch rotation test which is to be performed annually only showed a circle around the isocentre of a diameter of <2 mm.

Collimator position checks which are conducted every week during scheduled quality control checks showed that the results were unstable on all angles (0°, 90°, 180°, and 270°). The results were quite erratic and exceeded the acceptable tolerance of +/-0,2° as prescribed by international standards [17]. These measured figures also exceeded the tolerances as guaranteed by the manufacturer. The results achieved over a period of six months can be seen in figures 3, 4,5, and 6 hereinafter. Due to these erratic instabilities, collimator angle checks take place on a daily basis before treatments commence, in order to assure that patients receive their prescribed dose in the correct angles. It was also discovered that parts of the collimator subsystems have a great tendency to breakdowns. Delivery of replacement parts through the local agent of the manufacturer is time-consuming as on average; we wait for at least two weeks during which time treatment of patients is impeded as they all have to utilize the second machine. It was also discovered that the cables supplying the collimator modules do get tangled up and break occasionally which can normally be repaired in-house within two hours. To ensure the stability of the collimator angle, weekly calibration processes are conducted during the weekly quality control checks. An agreement was recently reached with the agent of the manufacturer to keep sufficient spare and replacement parts for the collimator subsystem in stock in Sudan which will ameliorate further the availability of our Co-60 units.

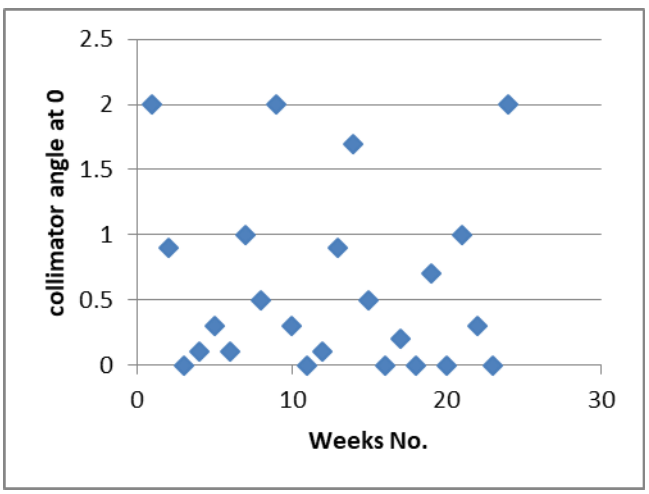

Fig.3. Collimator angle measured at 0°

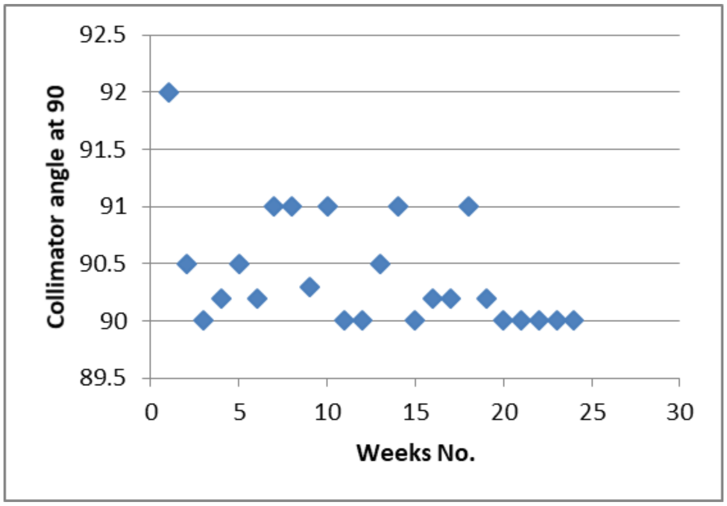

Fig.4. Collimator angle measured at 90°

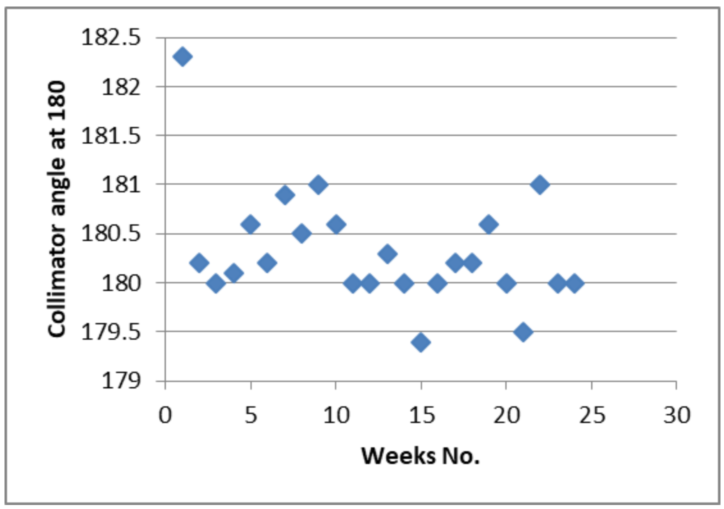

Fig.5. Collimator angle measured at 180°

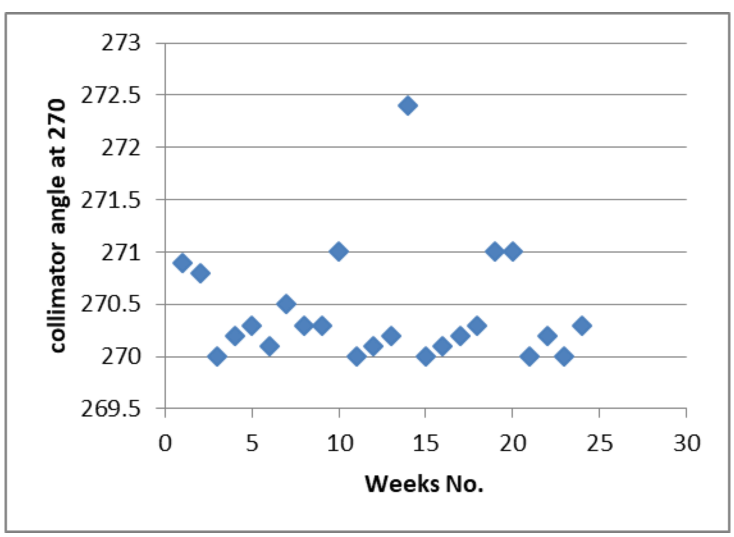

Fig.6. Collimator angle measured at 270°

Gantry angle checks take place on a weekly scale in line with the manufacturer's recommendation to keep the errors within a tolerance of 0,5° or within 1° when checked once per month, respectively [17, 18]. The result of the gantry angle measurements can be seen in figures 7, 8, and 9. It became evident that the gantry is unstable as erratic results were recorded. Time and again, the gantry angle accuracy is outside the acceptable range of 2,5° as per international standards and the ones specified by the manufacturer. It is for this reason that every week, the accuracy of the gantry angle is checked and recalibrated if necessary. In addition, every morning prior to commencement of treatment, the gantry angle is measured to ascertain that there is no risk for our patients. The same applies to the collimator. Visual checks of both cabling and components of the gantry sub-module do improve the situation.

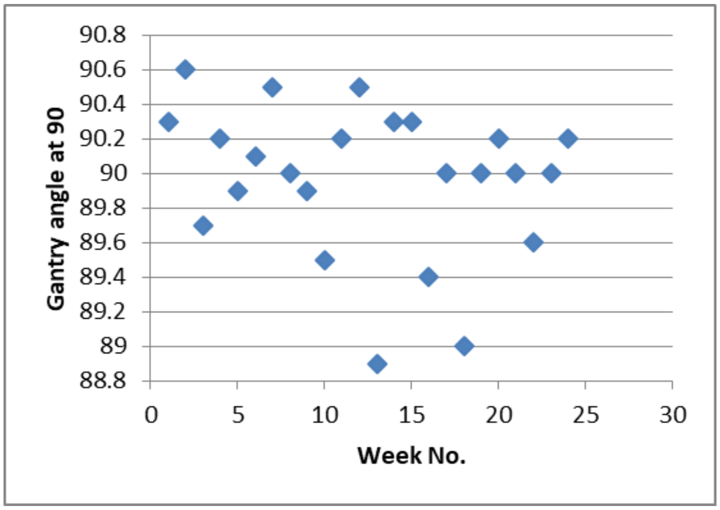

Fig.7. Gantry angle measured at 90°

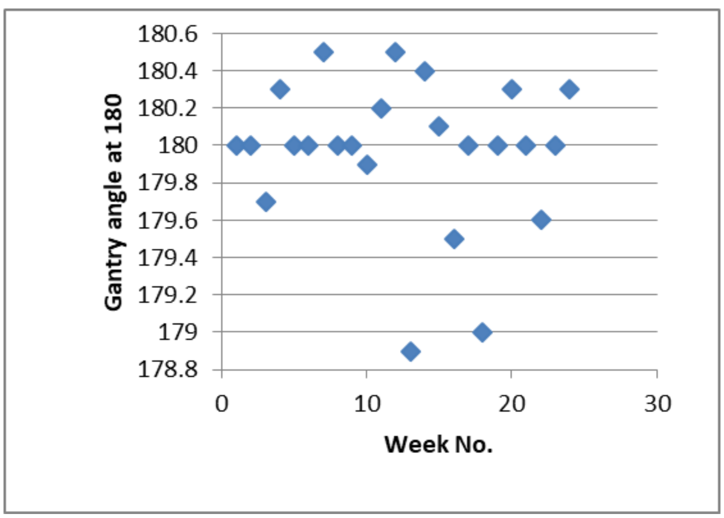

Fig.8. Gantry angle measured at 180°

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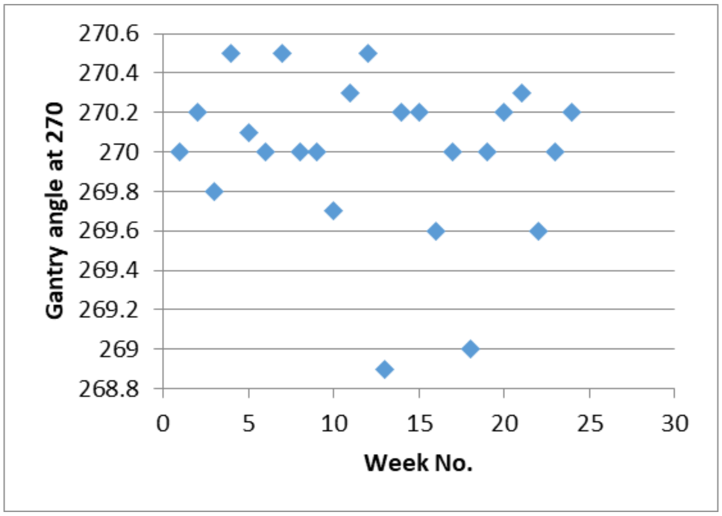

Fig.9. Gantry angle measured at 270°

Field size and coincidence checks are done on a weekly basis, covering field sizes of 5 x 5, 10 x 10, 15 x 15, 20 x 20, 25 x 25, 30 x 30, 35 x 30, 35 x 35 and 40 x 40 cm. These tests show instabilities of the field sizes and recalibration is needed at least every second week. The most common problems are attributed to collimator motors, supply cables, potentiometers, and collimator drive gears (which are made of plastic). Failing motors or potentiometers can easily be replaced with new components that we hold in stock and the same goes for the supply cables. Occasionally, however, we experience motion faults of the collimator jaws during patient set-up which cause a complete shut-down of the machine, with the result that the entire system has to be rebooted and restarted while the patient usually stays on the treatment couch, causing stress to the patient. This problem was raised with the engineer of the manufacturer's agent but so far no solution was offered [4].

Weekly checks are performed on the optical range finder in line with the manufacturer's recommendations. The results were encouraging as they were always stable and within an acceptable tolerance. The position of the lasers determining the position of the patient, are checked on a daily before the commencement of treatment in the morning. The results were that the position of the anterior and the posterior lasers was acceptable, however, the sagittal laser showed instabilities, due to it being mounted on a moving part. Hence, this laser has to be checked daily and readjusted if the need arises. Regular checks on all emergency interlocks/stops ensure that the machines can be shut down instantly if and when required. These tests are performed daily prior to the commencement of treatments.

4. Conclusion

It has become evident that the stability of various positions and angles are intermittently out of tolerance and has to be recalibrated daily in order to meet international standards. During the first six months, the achieved downtime was as high as 21% which improved during the next cycle of six months to 3,3%, i.e. availability of 96,7% after modifications to the input power supply equipment. The stability of angles on both gantry and collimator was successfully managed by daily checks and recalibrations prior to the commencement of treatment of patients. Daily checks of all safety interlocks and emergency shut-down switches ensure the safety of the patients. These results show that it is imperative that the machines require continuous supervision by a service/biometric engineer who will check the mechanical tolerances of the optical systems on the gantry, collimator, laser, field light, and size and range finder which is to be done every morning before patient treatment commences. This/these engineer(s) will also ensure that the input power supply is in line with specifications and thus minimizing failures of electronic components.

Author Contributions: Sulieman Zobly conceived the idea, collected data, and wrote the paper; Helmut Reichenvater analyzed the data and revised the paper.

Conflict of interest: The author declares no conflict of interest.

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