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Design and Ergonomic Analysis of the Waste Electrical and Electronic Equipment (WEEE) Remanufacturing Workcell Fixture Using Digital Mock-up Environment

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Abstract

Traditionally, operations in recycling industry such as WEEE (Waste Electrical and Electronic Equipment) are labour intensive and time consuming due to the nature of discrete / non-standards product states. Hence, small-mid scale WEEE recycling companies require significant product state assessment, process design and technology commitment in order to bid for mass refurbishment projects. Employing digital process simulation tools (which is prevalent in automotive and aircraft manufacturing industries) will result in design of ergonomically viable workstations. This paper introduces design and ergonomic assessment for remanufacturing workcell for light weight, hull shaped free-formed components. It demonstrates that the use of digital process simulation is a valuable tool and leads pathways towards establishing better workplaces where work related disorders are frequently reported in such industries.

Keywords: Ergonomics; Digital Mock-up; Design

1. Introduction

Traditionally, operations in recycling industry are labour intensive and time consuming due to the nature of discrete product states. Existing methods of refurbishment involve dismantling, cleaning, inspection, repair work if required, replacement if necessary, painting and re-installation. Currently these processes are discrete in nature and require labour intensive resources. However, for mass refurbishment projects, it is possible to introduce dedicated workstations that can reduce process time. The contribution in this paper is a design and analysis of dedicated remanufacturing workstation for restoring and extending the functionality of existing aluminum casting lamp with the view to responding similar mass refurbishment projects. As a part of this work, employing digital process simulation tools (which is prevalent in automotive and aircraft manufacturing industries) will result in design of ergonomically viable workstation, which will be a

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novel approach for recycling industries to evaluate work fatigue in labour intensive operations. The case study of digital process simulation presented in this paper will be a valuable demonstrator and it can lead pathways towards establishing better workplaces where work related upper limb disorders are frequently reported in such industries. If recycling industries are aiming to be remanufacturing industries in the circular economy, it is important that advances and benefits in aerospace and automotive industries should be adapted and transferred.

An industrial case study has been presented, where case scenario is selected from a recycling company. The company has established business in recycling WEEE products, which involves collection, disassembly and disposal. This company is aiming to re-use existing WEEE products as a part of their new business stream, thus remanufacturing knowledge transfer is required to support this business. The work presented in this paper reports post-evaluation phase of this business case; a design phase to build dedicated workstation for remanufacturing intended WEEE product. Following section 2 reviews core principles of remanufacturing methodologies for WEEE industries. Digital Mock-up tools are utilized in the design phase, thus reviewing workstation design principles. Section 3 presents a case study and workstation design constraints. Traditional practice of recycling the same product has been discussed with scope of improvement. Section 4 employs digital mock-up tools to evaluate designed workstation for ergonomics requirements fulfillments. This is followed by conclusion and future work in section 5.

2. WEEE service sector, Remanufacturing strategies and Digital Mock-up tools

Today WEEE industry is evidencing accelerated attention from academics, government policy makers, world forums, entrepreneurs as well as consumer social behavior. This has resulted in new laws and regulations [1], business models [2], product [3], manufacturing strategies [4] and supply chain logistics [5].

Despite all benefits the manufacturing industry brings to the society it is well know the risks to the environment especially during the production phase and end-of life of the products, where Design for Environment (DFE) and Design for Assembly (DFA) plays important roles [6]. Previous research carried out by [7] has shown how reuse extends product's lifetime as well as offsets the embodied energy that is created during the manufacturing process; reuse have also been identified as the most appropriate end-of-life cycle for electronic components. Design for end of life need to be considered with remarkable attention towards disassembly aspects. Authors in previous research, [8] have shown how disassembly based strategies can provide environmental contributions where disassembly parameters must be considered in the disassembly process and will differ depending on the type of industry. Few examples of these parameters are: accessibility, tools type, connection type, connection quantity, etc.

A model for decision-makers and designers for re-engineering purposes has been developed and can be used to evaluate disassemblability indices and enhance products end-of-life. Remanufacturing involves extending use of existing products beyond its normal expected life by re-using whole or part of the product. New remanufactured product may have same or different purpose, depending upon its functionality and intended use. This trend is estimated to save 85% of energy that required to manufacture the initial product [9]. Thus, remanufacturing can be regarded as an identification of existing products in order to re-use it for developing a new product that can fulfill market demand. Although some literature and case studies by [10] are now available on identifying such existing products for remanufacture, there remains a shortfall from eminent product design industries to adopt this business model in designing their products for future remanufacture purpose. While it is challenging to envisage future remanufacture products from current new product lines due to unforeseen change in the technology landscape, it is possible to identify existing near warranty products in use phase for remanufacturing assessment.

Remanufacturing process involves disassembly, cleaning, inspection, sorting, reconditioning, reassembly, testing and dispatch stages, [11]. While addressing Design-For-Remanufacture (DFRef) guidelines, [12] have highlighted that environmental assessment should be a part of remanufacturing decision making in order to evaluate or propose a business case. These guidelines forms the basis for defining a remanufacturing process flow for the case study reported in this paper.

Designing for Assembly (DFA) means that the design of components must fulfill specific requirements for assembly in order to ensure an optimal and efficient process. DFA focuses on reducing products assembly costs by reducing assembly operation, materials, standardize parts, reduction of fasteners, design for symmetry for insertion, etc. The cost of assembling a product is proportional to number of parts. In order to simplify a design process, design for manufacturing and assembly (DFMA) needs to be applied as it saves cost, time and improves quality and environment.

In [13], the advantages that come from the simulation, in a virtual environment of a Manual Handling activity have been presented. Other works [14] and [15], have shown the behaviours and the characteristics of digital human models and the advantages offered by the use of ergonomic software in engineering design. Digital Mock-up is a design approach based on the use of simulation modelling tools. It allows to simulate work environments, operators, and machines and to reproduce, in virtual environments, all the assembly activities such as access, handling, disassembly, repair and assembly tasks, [16]. In fact, Digital Human Models, by simulating behaviours and characteristics of real persons, allow performing accessibility and manipulability analysis in a rigorous and quick way.

Virtual simulation of maintainability tasks, by means of Digital Human Models, allows to:

- Evaluate visibility, reachability and grasping of component parts during assembly and disassembly phases;
- Verify the possibility for the operators of using the necessary tools.

- Calculate times and efforts needed for the execution of maintenance tasks;
- Foreseen the capability of the workers to support these efforts according to their anthropometric characteristics;
- Highlight damage risks during each lifting and handling of component parts.

In conclusion, a Digital Mock-up approach, taking into account anthropometric and physiologic characteristics of the workers, allows establishing if the supposed motions are executable. Furthermore, it allows performing ergonomic analysis of the postures assumed during the assembly/disasembly tasks.

3. Case study: Workstation design for product remanufacture

3.1. Pre-evaluation stage for remanufacturing

Case study presented in this paper evaluates remanufacturing option for street light housing. The business case was evaluated against the option to buy new LED light housing for replacing existing light housings with sodium lamps. The environmental impact of the re-manufactured aluminium alloy (LM6) housing has been analyzed prior to designing dedicated workstation. The results have been compared to the new housing made of aluminium alloy (Al Si12Cu1{Fe}), using a methodology proposed by [17].

The methodology used to calculate life cycle inventory and environmental impact is Building for Environmental and Economic Sustainability (BEES). Ecoinvent V3.4 database was used as reference since it is the most updated database. The new LED had a single score of 2.45 pts, global warming 638 kg CO_2 eq; water usage of 5.46 x 103 litres and human health cancer of 3.39 x 104g C_6H_6 eq. The remanufactured unit had a single score of 2.22pts, global warming 551kg CO_2 eq; water usage of 4.63 x 103 litres and human health cancer of 3.16 x 104g C_6H_6 eq. These results are used to pass first gate review with the conclusion that the remanufactured luminaire had a potential to better environmental impact than purchasing new LED light housing. Thus, piloting phase to remanufacture 1000 light housing was undertaken, which includes design and analysis of dedicated workstation for the remanufacturing process.

3.2. Product features and designing of self-locating fixture frame

The products that have been analyzed in this casa are street luminaire with HPS bulb. The other product is a new luminaire with LED lighting unit. Both units consist of electrical and mechanical components. These components have been included in the modelling analysis.

The methodology in this study has been chosen based on the products structures. The old lamp has a different structure and composition from the new one. The product structures and differences are shown in the Fig.1. The old lamp structure will change after remanufacturing.

Since the piloting phase includes remanufacturing of 1000 light housing, this imposes amount of automation and associated cost that can be incurred on this phase. Current workstation to disassemble existing light housing does not include any special jig as the whole process is carried out on the workbench with only one operator involved in the whole process. Table 1 provides complete disassembly process sequence. With a skilled operator, each light housing required 16 minutes and 5 seconds to disassemble whole product and prepare two housing halves for further re-coating process. It was observed that light housing was resting on the freeform, hull shaped glass surface of the bulb housing. Thus, self-locating fixture frame was designed to avoid placement manipulation time. It was possible to use customized rest pads as lower housing had flat resting surface with raised profile around the lamp housing. Toggle clamps were used as lower housing rim had few boss features merged with the wall. It was important to consider center of gravity (COG) of the light housing after opening as upper housing remains locked by holding link during disassembly process as shown in the Fig.1. It was confirmed that COG of opened light housing should lie within 4 rest pads to avoid any displacement before applying toggle clamps. Two halves of the housing are pivoted with spring loaded pins on each end. This particular product feature was demanding significant time as pin was difficult to remove due to corrosion. Thus customized plier was designed to push these pins in order to separate two halves. Finally, this fixture design was assessed for ergonomic use by mapping required process in Table 1 with digital human modelling tools.

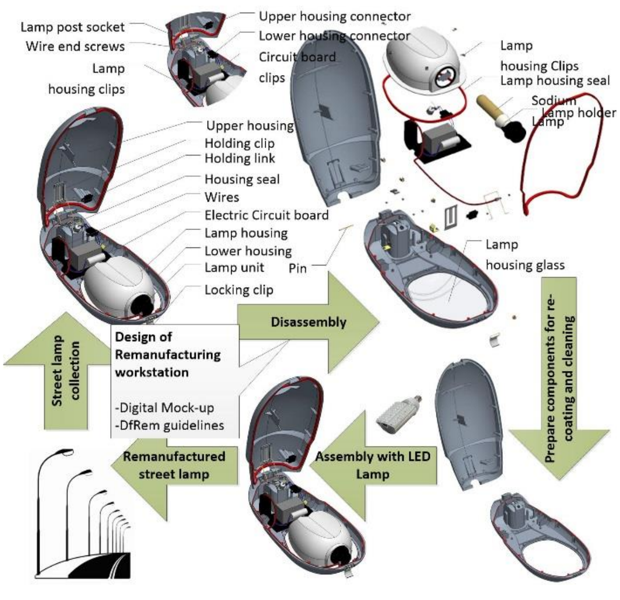

Fig. 1. Key stages for remanufacturing processes.

4. Ergonomic analysis of the task and definition of the optimal postural sequence

The first phase consists in an analysis of the working environment and in the consideration of all the possible movement alternatives: this, in general, involves considering alternative routes, postures and speeds of execution, which all contribute to the effective conclusion of the work.

Table 1. Disassembly process sequence.

Activity sequence	Activity description	Part Inventory	Old setup (min)	New setup (min)	Component Reuse
1	Place housing on the fixture pads			0.5	
2	Remove front Locking clip				
2.1	Open locking clip	-	0.5	0.5	Yes
	Remove Locking clip	2	0.5	0.5	Yes
3	Clamp housing in open position				
3.1	Open housing	-	0.25	0.25	-
3.2	Lock with Toggle clamps	-	-	0.25	-
3.3	Latch upper half with holding clip	-	0.5	0.25	-
4	Remove electric circuit board and wires, clips and seal				
4.1	Remove wire plug on lamp unit	-	0.25	0.25	-
4.2	Remove Screws with PT		6	1.5	Yes
4.3	Remove post lock screw	2	0.5	0.25	Yes
4.4	Cut ceramic plug wires	-	0.5	0.5	-
4.5	Remove circuit board	1	1	0.5	No
4.6	Remove UH seal	1	0.5	0.5	Yes
5	Disassemble lamp housing				
5.1	Remove lamp housing	1	0.5	0.5	Yes
5.2	Remove lamp housing seal	1	0.5	0.5	Yes
5.3	Disassemble lamp holding unit	1	0.5	0.5	Yes
6	Disassemble upper housing				
6.1	Remove UH holding bracket screw	2	1	0.5	Yes
6.2	Remove UH holding bracket link and close housing	1	0.5	0.5	Yes
6.3	Remove pivot pins	2	4	3	Yes
6.4	Remove upper housing	1	0.5	0.5	Yes
6.5	Remove pole post screw	3	1	0.5	Yes
7	Remove ceramic plug	1	10	4	No
8	Unclamp Lower housing	1	-	0.25	Yes
TOTAL		37	29	16.5	

It is essential, in a virtual environment, to simulate all these operations in order to verify in the first place their feasibility. In fact, for instance, it cannot be taken for granted that all the points can be reached starting from different postures. The execution of this analysis guarantees the feasibility of the assignment. Among the phases of optimization this is the one that requires the longest time. Since it needs the creation of a large number of simulations in real time, without taking into account that some of them will turn out to be useless, because, for instance, the simulation shows that some points cannot be reached with the movements that the designer had conceived. Other parameters that can be modified are the distances of the manikin from objects taken as a reference, and the possibility to move the objects in the working area.

In order to evaluate the ergonomics of the workcell, the design process was carried out in accordance with the macro processes described in Table 1. By utilising this workcell design the critical postures of the operator were identified. The critical postures were decided by the frequency that the operator would use a certain posture and the importance to the task. Once the initial postures were defined, the sequence of operation was simulated. This aided with producing realistic times for the operator to walk around the disassembly area.

By simulating the operations in a virtual environment, the workers' postures were evaluated using the Posture Evaluation Index (PEI), developed and illustrated in [13]. The PEI integrates the results of the Low Back Compression Analysis (LBA), [18], the Ovako Working Posture Analysis (OWAS), [19], and the Rapid Upper Limb Assessment Analysis (RULA), [20], in a synthetic non-dimensional index able to evaluate the "quality" of a posture:

$$PEI = \frac{\text{LBA}}{3400} + \frac{\text{OWAS}}{3} + \frac{\text{RULA}}{5} \quad (1)$$

Ten critical postures, which the operator would assume while performing the repair procedures, were identified. Fig.2 shows the final configuration of the workcell.

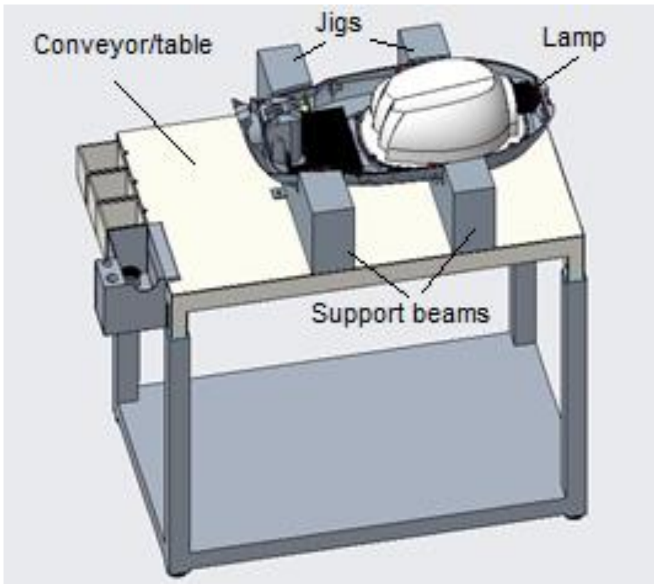

Fig. 2. Workcell configuration.

Moreover, the tasks (a) Positioning lamp on the jig; (b) Lifting lamp out of Support Beams; (c) Balancing product for placing into support; (d) lifting lamp from conveyor and corresponding postures are shown in Fig.3. These tasks needs the use of both hands; as the element does not contain handles, the only way to lift the object is to grasp it at the top border. After the results for the PEI were calculated for the ten critical configurations, the PEI of each configuration was analysed against the benchmark, PEI < 3, [13]. Table 2 synthesizes the results of the ergonomics analysis where: I_1 = LBA/3400 N, I_2 = OWAS/3, I_3 = RULA/5.

Fig. 3. (a) Positioning lamp on the jig; (b) Lifting lamp out of Support Beams; (c) Balancing product for placing into support; (d) lifting lamp from conveyor.

Table 2. Ergonomics analysis results.

	Posture									
	1	2	3	4	5	6	7	8	9	10
I_1	0.159	0.564	0.501	0.140	0.142	0.395	0.339	0.306	0.155	0.464
I_2	0.333	0.666	0.666	0.333	0.333	0.666	0.666	0.666	0.333	0.666
I_3	0.4	0.4	0.6	0.6	0.6	0.6	0.8	0.8	0.8	0.6
PEI	0.892	1.63	1.767	1.073	1.075	1.661	1.861	1.772	1.288	1.664

5. Conclusion and future work

The proposed methodology makes available a valid tool for workplace analysis. The following objectives have been achieved: design and ergonomically assess remanufacturing workcell for light weight, hull shaped free-formed components, appraise the quality of the postures assumed during disassembly activity. Designing a new layout, to establish if it ensures the feasibility of the operation (based on the criteria of accessibility of the critical points, of compatibility of the efforts, and danger for the lower back), compare the possible alternatives for the configuration of the layout. The methodology represents an innovative approach to design for maintainability based on the integration between 3D parametric CAD systems, DMU tools, ergonomic tools and digital human models. Future research will explore methods to improve the user interface with features to determine feasible disassembly routes of a product automatically. This will relieve the effort of the product designer largely.

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