1-1-2018

A framework for energy monitoring of machining workshops based on IoT

Xingzheng Chen

Congbo Li

Ying Tang
Rowan University, tang@rowan.edu

Li Li

Qinge Xiao

Recommended Citation

X. Chen, C. Li, Y, Tang, L. Li, Q. Xiao. A framework for energy monitoring of machining workshops based on IoT. Procedia CIRP, 72 (2018) 1386-1391.

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 72 (2018) 1386–1391

www.elsevier.com/locate/procedia

51st CIRP Conference on Manufacturing Systems

A framework for energy monitoring of machining workshops based on IoT

Xingzheng Chen[a], Congbo Li[a]*, Ying Tang[b], Li Li[c], Qinge Xiao[a]

[a]*State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing, P.R. China*
[b]*Department of Electrical and Computer Engineering, Rowan University, Glassboro, New Jersey, USA*
[c]*College of Engineering and Technology, Southwest University, Chongqing, P.R. China*

* Corresponding author. Tel.: +86-23-6510-3159 ; fax:+86-23-6510-5028. *E-mail address:*congboli@cqu.edu.cn

Abstract

Machining workshop is a widely distributed manufacturing system that consumes massive energy in low efficiency. Due to the complicated and dynamic energy flow of the machining workshop, machinery manufacturers still lack an effective method to monitor and manage the energy efficiency. Hence, this paper proposes an energy efficiency monitoring system for machining workshop with the support of the newly emerging Internet of Things (IoT) technology. With the application of the proposed system, potential opportunities for energy efficiency improvement can be identified. Machinery manufacturers can easily reduce energy consumption and energy cost by managing the machining process.

Keywords: Energy efficiency; Monitoring; Internet of Things

1. Introduction

Machining workshop is a widely distributed manufacturing system that consumes massive energy in a low efficiency. Numerous surveys indicate that the efficiency for the machining process is usually less than 30% [1]. In the work reported by Gutowski et al., the energy efficiency of a typical milling process is only 14.8% [2]. Hence, improving energy efficiency and reducing energy consumption of machining process is important and imperative.

However, the energy consumption of the machining process has the characteristics of large amount of energy consumers and dynamic energy flows. This makes a challenge for energy reduction. To address this challenge, many scholars studied the issues of energy evaluating [3-5] and energy optimizing [6-11]. Numerous approaches were proposed to reduce energy consumption of the machining process. However, as mentioned in [12], energy monitoring is a key factor towards successful energy management. With a proper monitoring mechanism, it is possible to identify energy hotspots of the machining process. Vijayaraghavan and Dornfeld introduced a framework based on event stream processing to analyze the energy of machine tools. An energy monitoring approach was proposed to acquire the machine tool energy [13]. Hu et al. proposed an approach for machine tool energy efficiency monitoring based on energy models. The total energy and energy utilization ratio of the machine tool could be obtained by the proposed approach [14]. Similar work can be found in [15] and [16].

After a perusal of current literatures, it can be found that existing researches about energy monitoring mainly concentrate on machine tools. Little research effort was paid to the auxiliary equipment such as the air compressors and air conditioners that consume a large amount of energy [17]. Furthermore, in the machining process, the energy consumption of the machine tool is dependent on the machining task features (process routes, cutting parameter, etc.) [18]. In order to enhance energy management of the machining process, all of the machine tools and auxiliary equipment should be monitored and all of the energy-related production data such as machining task features should be gathered. On the basis, energy inefficiencies cause-effect relationship can be established and further energy saving opportunities can be identified. However, how to efficiently

2212-8271 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 51st CIRP Conference on Manufacturing Systems.
10.1016/j.procir.2018.03.085

monitor these energy-consuming machine tools and auxiliary equipment as well as collect the multiple energy-related production data is very difficult.

In recent years, the newly emerging Internet of Things (IoT) technology is enhancing machine and production management in an effective manner [19]. A lot of researchers have been engaged in this field and proposed some effective methods for machine and production management based on IoT. For example, in the work presented by Mourtzis et al., they proposed an approach for machine tools energy consumption estimation based on real-time monitoring measurements [20]. Zhong et al. developed a Radio Frequency Identification (RFID)-enabled real-time manufacturing execution system for mass-customization production [21]. With the proposed system, visibility and traceability of materials were improved. Other related work using IoT for machine or production management can be found in [22-24]. These studies provide reference methods towards the successful energy monitoring of the machining workshop. However, after a perusal of current literatures, it can be conclude that there is still a lack of detailed framework for energy monitoring of machining workshops based on IoT.

Therefore, this paper attempts to fill the gap and proposes an IoT based energy efficiency monitoring system for the machining workshop. To better monitor the energy efficiency, we divide the machining workshop into machine tool level, machining task level and machining workshop level. The monitored energy-consuming points and the energy-related data acquisition method of each level are introduced. Based on the energy data, the potential energy saving opportunities are identified. Machinery manufacturers can easily reduce energy consumption and improve energy efficiency by managing the machining process.

2. Framework of the IoT based energy monitoring system

As shown in Fig.1, the proposed IoT based energy efficiency monitoring system is consisted of four layers, i.e. data acquisition layer, data transmission layer, data processing layer and application layer. The details is given below.

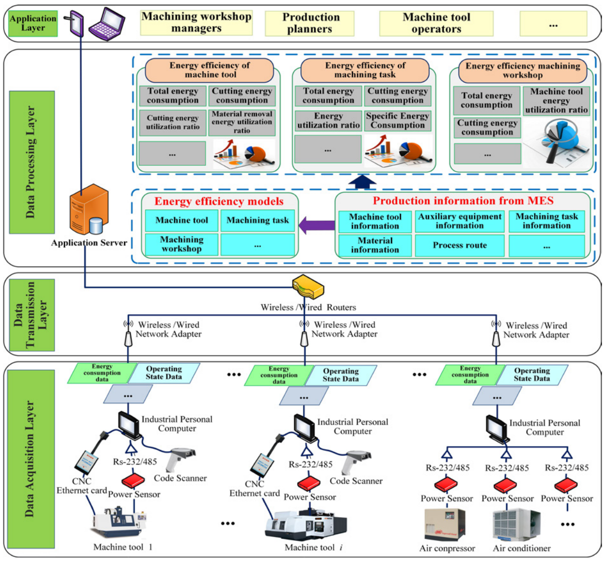


Fig.1 Framework of the IoT based energy efficiency monitoring system

2.1 Data acquisition layer

The data acquisition layer is responsible for perceiving and pre-processing the production data and energy consumption of machine tools and auxiliary equipment. It consists of a data perception layer and data pre-processing layer.

The data perception layer is composed of power sensors, CNC Ethernet cards and code scanners. The power sensors are installed on the machine tools and auxiliary equipment to measure their real-time power consumption. The CNC Ethernet cards are used to gather the cutting parameters (i.e. spindle speed and feed rate) from the CNC system. As for the code scanners, they are used to collect the start and finish time of each operation on each machine tool for a workpiece, as a workpiece is usually machined by several ordered operations with different machine tools.

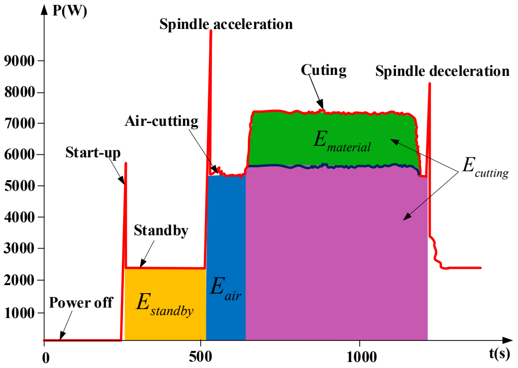


Fig.2 Operating states and energy consumption of a machining process

The data pre-processing layer is responsible for pre-processing the power consumption data acquired by the data perception layer. The hardware and software of the data pre-processing layer are industrial personal computers (IPCs) and machine tool energy efficiency monitoring system (MTEEMS). For each machine tool, it is equipped with an IPC and MTEEMS. With the IPC and MTEEMS, as shown in Fig.2 and Fig.3, the real-time operating state (i.e. power off, standby, air-cutting and cutting) can be identified. On the basis, as shown in Fig.4, the operating time and energy consumption the machine tool under these states can be obtained. The total energy consumption of the machine tool $E_{machine}$ can be acquired according to Eq.(1). Note that the energy consumption of the machine tool in the power off state is zero.

$$E_{machine} = E_{standby} + E_{air} + E_{cutting} \qquad (1)$$

where $E_{standby}$, E_{air} and $E_{cutting}$ are the machine tool energy consumption under standby, air-cutting and cutting states.

The pre-processing process of the real-time power consumption data of the auxiliary equipment is quite similar to that of the machine tools. The only difference is that all the auxiliary equipment share one multi-channel IPC and a simplified MTEEMS. On the basis, the real-time operating state (i.e. power off or working) of the auxiliary equipment can be identified and the total energy consumption can be obtained.

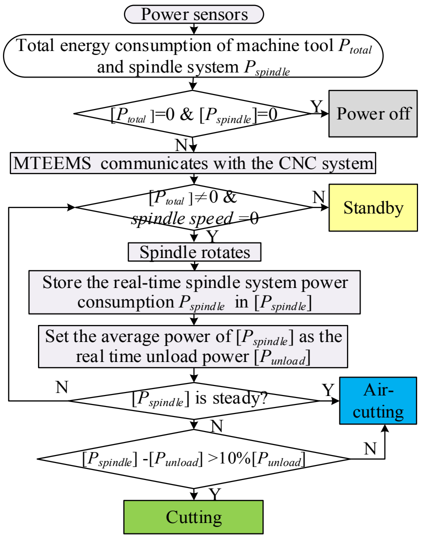
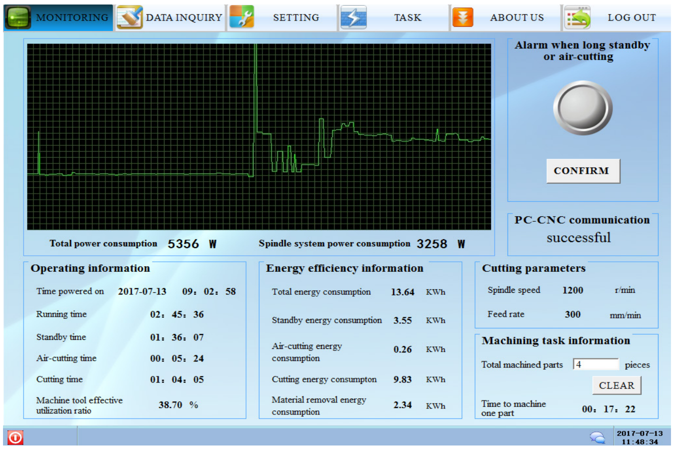


Fig.3 Flowchart of identifying the operating state of machine tool



Total power consumption 5356 W
Spindle system power consumption 3258 W

PC-CNC communication
successful

Operating information

Time powered on	2017-07-13 09：02：58
Running time	02：45：36
Standby time	01：36：07
Air-cutting time	00：05：24
Cutting time	01：04：05
Machine tool effective utilization ratio	38.70 %

Energy efficiency information

Total energy consumption	13.64	KWh
Standby energy consumption	3.55	KWh
Air-cutting energy consumption	0.26	KWh
Cutting energy consumpton	9.83	KWh
Material removal energy consumption	2.34	KWh

Cutting parameters

Spindle speed	1200	r/min
Feed rate	300	mm/min

Machining task information

Total machined parts 4 pieces

Time to machine one part 00：17：22

2017-07-13 11:48:34

Fig.4 Machine tool energy efficiency monitoring system

2.2 Data transmission layer

The data transmission layer is used for data transmitting between data perception layer and data processing layer. It consists of wireless cards and industrial wireless routers. The wireless cards are installed on the IPCs and the wireless routers connect them to the application server.

2.3 Data processing layer

The data processing layer is served to analyze and store the energy efficiency of machine tools, machining task and machining workshop.

- *Machine tool*

In the data pre-processing layer, the machine tool total energy consumption and the energy consumption under different operating states are obtained. On the basis, the cutting energy utilization ratio $\eta_{machine}$ and material removal energy utilization ratio $u_{machine}$ of the machine tool will be obtained according to Eqs.(2) and (3).

$$\eta_{machine} = E_{cutting} \Big/ E_{machine} \tag{2}$$

$$u_{machine} = E_{material} \Big/ E_{cutting} \tag{3}$$

where $E_{material}$ is the material removal energy that consumes at the tool tip to directly remove the workpiece material (Fig.2).

- *Machining task*

In a machining workshop, many machining tasks are machined at the same time. For a specific machining task, it will be machined by several ordered operations according to its process route. In order to obtain the energy consumption and energy efficiency of the machining task, the process route, quantity of machining task, machine tool of each operation, and start and finish time of each operation should be known.

In recent years, many machining workshops use the Manufacturing Execution System (MES) to dispatch machining task to a specific machine tool and operator. Hence, the required process route, quantity of machining task, machine tool of each operation and machining start and finish time of each operation can be acquired from the MES. With the energy consumption of the machine tools under different operating states, as shown in Eqs.(4) and (5), the material removal energy utilization ratio u_{task} and specific energy consumption (SEC) [25] can be obtained.

$$u_{task} = \sum_{r=1}^{q} E^{r}_{material} \Big/ \sum_{r=1}^{q} \left(E^{r}_{standby} + E^{r}_{air} + E^{r}_{cutting} \right) \tag{4}$$

$$SEC = \sum_{r=1}^{q} \left(E^{r}_{standby} + E^{r}_{air} + E^{r}_{cutting} \right) \Big/ N \tag{5}$$

where $E^{r}_{material}$, $E^{r}_{standby}$, E^{r}_{air} and $E^{r}_{cutting}$ are the material removal energy consumption, standby energy consumption, air cutting energy consumption and cutting energy consumption of the r^{th} operation. q is the total number of machining operations. N is the quantity of machining task.

- *Machining workshop*

The energy efficiency of the machining workshop are related to the energy consumption of the machine tools and auxiliary equipment. With the acquired energy consumption of machine tools and auxiliary equipment, the machine tool energy utilization ratio $\rho_{workshop}$ and cutting energy utilization ratio $u_{workshop}$ of the machining workshop can be obtained according to Eqs.(6) and (7).

$$\rho_{workshop} = \sum_{i=1}^{m} E^{i}_{machine} \Big/ \sum_{i=1}^{m} E^{i}_{machine} + \sum_{j=1}^{p} E^{j}_{auxiliary} \tag{6}$$

$$u_{workshop} = \sum_{i=1}^{m} E^{i}_{cutting} \Big/ \sum_{i=1}^{m} E^{i}_{machine} \tag{7}$$

where $E^{i}_{machine}$ and $E^{i}_{cutting}$ are the total energy consumption and cutting energy consumption of the i^{th} machine tool, $E^{j}_{auxiliary}$ is the energy consumption of the j^{th} auxiliary equipment, m and p are the total number of machine tools and auxiliary equipment in the machining workshop.

2.4 Application layer

The application layer is responsible for providing energy efficiency data to different users, such as the machining workshop managers, production planners and machine tool operators.

3. Industrial application

Based on the proposed approaches, an IoT based energy efficiency monitoring system for machining workshop was developed. The initial edition of the system was in Chinese. For the sake of understanding, we translated the main parts of it into English.

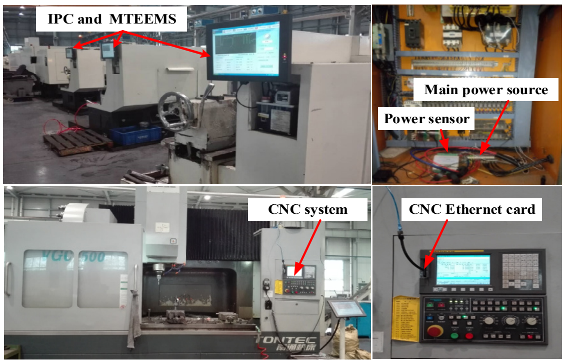


Fig.5 The application machining workshop

Energy efficiency of machining workshop in real-time

Power consumption
Real-time power consumption of machining workshop: 25107 W

Operating state
Number of machine tools powered on: 20 (25 in total)
Number of auxiliary equipment powered on: 38 (43 in total)

Energy efficiency
Total energy consumption: 568.05KWh
Machine tool energy consumption: 346.34KWh
Auxiliary facility energy consumption: 221.71KWh
Machine tool energy utilization ratio: 60.97%
Cutting energy utilization ratio: 40.21%

Milling center 202#
Time powered on: 2017-07-26 09:21:38
Real-time power consumption: 3756 W
Total energy consumption: 35.73KWh
Cutting energy consumption: 22.17KWh
Energy utilization ratio: 62.05%
Operating state: Cutting ●

Milling center 203#
Time powered on: 2017-07-26 08:03:45
Real-time power consumption: 4137 W
Total energy consumption: 22.56KWh
Cutting energy consumption: 2.81KWh
Energy utilization ratio: 12.46%
Operating state: Cutting ●

Milling center 204#
Time powered on: 2017-07-26 09:31:12
Real-time power consumption: 1130 W
Total energy consumption: 61.63KWh
Cutting energy consumption: 31.35KWh
Energy utilization ratio: 50.87%
Operating state: Standby ●

Fig.6 Energy efficiency of machining workshop in real-time

As shown in Fig.5 and Fig.6, the proposed IoT based energy efficiency monitoring system has been applied in a machining workshop with 25 machine tools, 24 LED lamps, 10 ventilation fans, 5 air conditioners, 2 transport equipment and 2 air compressors. The power sensors used in the application case were the HC33C3 power sensors provided by Changzhou Huice Electronic. The industrial personal computers were developed by our group. The wireless routers and application server were provided by HUAWEI. With the application of the proposed system, some potential opportunities for energy efficiency improvement have been discovered. The details will be discussed with practical cases as follows.

3.1 Machine tool level

In this case, as shown in Table 1, the energy efficiency and operating time of the milling center 202# the nine days were obtained by the proposed system. It can be found that the cutting energy utilization ratio of eight days was more than 65%. The highest one was 86.64%. However, the cutting energy utilization ratio on 2017-07-14 was only 53.31%. This is very abnormal.

Reviewing the operating state of the machine tool, it was found that the machine tool was standby for more than 5 hours on 2017-07-14. When checking the machining task record in the MES, we found that the machining tasks dispatched to this machine tool was very small. The reason for the low cutting energy utilization ratio was that the standby energy consumption took a big proportion of the total energy consumption. To reduce the standby energy consumption, the machine tool or the machine tool components such as the chip conveyor and lamp should be shut up when there is no machining task dispatched to the machine tool.

Moreover, as shown in Table 1, the material removal energy utilization ratio of the machine tool is less than 40%. This indicates that only a little energy is consumed to directly remove the workpiece material. The main reason was that many energy-consuming machine tool components such as the cooling pump and oil mist separator were activated during the machining process. To improve the material removal energy utilization ratio, dry machining is an alternative energy efficient machining method [26].

3.2 Machining task level

In this case, as shown in Table 2 and Table 3, two batches of drive shafts were machined under process route I and II process route. When compared to process route I, it was found that the SEC of process route II decreased by 13.51% and the material removal energy utilization ratio increased by 23.21%. Process route II was a better choice to machine the drive shaft. There were two reasons for this phenomenon. The first one was that the standby energy consumption of process route II was less than the process route I. The difference lay in the method to locate the workpiece of different operators. For some operators, their methods were time consuming and hence energy consuming because the machine tool was standby during this period. The second one was related to the machine tool and cutting parameters of each operation. Different machine tools and cutting parameters were selected to perform machining of the same machining task. The cutting energy and material removal energy of each operation varied with the machine tool and cutting parameters. Proper selection of machine tool and cutting parameters increased the material removal energy and reduce the cutting energy.

To enhance the energy management of the machining task, the following two methods may be effective. Firstly, monitoring the process route (i.e. machine tools, cutting parameters) and the energy efficiency of the machining task, then a better process route can be obtained by comparing the records. Secondly, it is necessary to establish an energy consumption benchmark for a specific machining task. By this mean, the standby energy consumption can be reduced.

3.3 Machining workshop level

In this case, the energy consumption of the machining workshop during 10 days was obtained and listed in Table 4. It was found that the machine tool energy utilization ratio of the machining workshop of each day was different. The average was 63.88%. However, it only accounted for 55.03% and 52.21% on 2017-07-20 and 2017-07-21.

Reviewing the machining process during the 10 days, the amount of machining tasks on 2017-07-20 and 2017-07-21 were smaller than the other eight days. However, the auxiliary equipment were always working regardless of the amount of the machining tasks. Hence, shutting up some auxiliary equipment in the machining workshop timely according to the amount of machining tasks in MES is an effective way to reduce energy consumption of the auxiliary equipment.

Moreover, as shown in Table 4, the average cutting energy utilization ratio of the machining workshop was 53.09%. On 2017-07-24, it was only 40.13%. The main reason was that many machine tools were standby in a long time and waiting for the incoming machining task besides the necessary standby time for locating a workpiece. This increased the standby energy consumption. To reduce the standby energy consumption, two directions can be taken into consideration. On one hand, some machine tools or machine tool components such as the chip conveyor and lamp should be shut up according to the real-time machining task in MES. On the other hand, the machining task must be better scheduled for energy reduction consideration.

Table 1 Energy efficiency and operating time of milling center 202#

Date	Standby time	Air-cutting time	Cutting time	Running time	Standby energy (KWh)	Air-cutting energy (KWh)	Cutting energy (KWh)	Total energy (KWh)	Material removal energy (KWh)	Cutting energy utilization ratio	Material removal energy utilization ratio
2017-07-11	2h16min	19min	6h37min	9h12min	10.23	1.95	64.83	97.35	21.92	70.70%	31.85%
2017-07-12	3h46min	24 min	4h59min	9h9min	17.05	2.45	85.71	105.21	17.22	81.47%	20.09%
2017-07-13	4h24min	27 min	4h33min	9h23min	19.87	2.76	45.74	68.37	16.19	66.90%	35.40%
2017-07-14	5h53min	15 min	4h9min	10h17min	26.57	1.55	32.11	60.23	10.23	53.31%	31.86%
2017-07-15	3h37min	27 min	5h41min	9h45min	16.33	2.82	65.42	84.57	16.86	77.36%	25.77%
2017-07-16	2h39min	21 min	6h31min	9h31min	11.95	2.19	104.72	118.86	31.84	88.10%	30.40%
2017-07-17	3h9min	38 min	6h21min	10h8min	14.23	3.98	109.71	127.92	40.58	85.76%	36.99%
2017-07-18	3h4min	42 min	5h53min	9h39min	13.86	4.33	86.37	104.56	31.91	82.60%	36.95%
2017-07-19	2h29min	21 min	6h56min	9h46min	11.22	2.17	86.83	100.22	21.96	86.64%	25.29%
In total	31h16min	3h54min	51h40min	86h50min	141.31	24.20	685.44	867.29	208.71	79.03%	30.45%

Table 2 Energy efficiency of machining task under process route I

No.	Machine tool	Cutting tool	Quantity	Cutting parameters	Standby time (min)	Total time (min)	Material removal energy (KWh)	Standby energy (KWh)	Cutting energy (KWh)	Total energy (KWh)	Material Removal energy utilization ratio	SEC (KWh/piece)
1	Lathe 115#	Cutter 102332	100	n=250r/min f =25mm/min	435.81	975.13	13.76	13.65	62.45	83.29	16.52%	0.83
2	Milling center 204#	Cutter 203725	100	n=2000r/min f =160mm/min	345.42	758.92	5.02	8.93	13.87	27.75	18.09%	0.28

Total energy consumption of the task: 95.72 KWh

Specific energy consumption of the task SEC: 1.11 KWh/piece

Standby energy consumption of the task: 16.89 KWh

Material removal energy consumption of the task: 18.78 KWh

Table 3 Energy efficiency of machining task under process route II

No.	Machine tool	Cutting tool	Quantity	Cutting parameters	Standby time (min)	Total time (min)	Material removal energy (KWh)	Standby energy (KWh)	Cutting energy (KWh)	Total energy (KWh)	Material Removal energy utilization ratio	SEC (KWh/piece)
1	Lathe 110#	Cutter 102332	100	n=300r/min f =25mm/min	352.72	698.54	16.89	9.73	55.52	72.14	26.19%	0.72
2	Milling center 209#	Cutter 203725	100	n=2500r/min f =200mm/min	313.17	613.37	6.25	7.16	11.77	23.58	34.99%	0.24

Total energy consumption of the task: 95.72 KWh

Specific energy consumption of the task SEC: 0.96 KWh/piece

Standby energy consumption of the task: 16.89 KWh

Material removal energy consumption of the task: 23.14 KWh

Table 4 Energy consumption of the machining workshop during 10 days

Date	Standby energy consumption of machine tools (KWh)	Air-cutting energy consumption of machine tools (KWh)	Cutting energy consumption of machine tools (KWh)	Total energy consumption of machine tools (KWh)	Total energy consumption of auxiliary equipment (KWh)	Total energy consumption of machining workshop (KWh)	Cutting energy utilization ratio	Machine tool energy utilization ratio
2017-07-16	312.75	53.27	480.10	846.12	489.31	1335.43	56.74%	63.36%
2017-07-17	371.33	42.18	258.73	672.24	360.61	1032.85	38.49%	65.09%
2017-07-18	256.27	62.95	648.90	968.12	455.86	1423.98	67.03%	67.99%
2017-07-19	272.31	58.25	578.48	909.04	392.73	1301.77	63.64%	69.83%
2017-07-20	271.35	52.13	233.81	557.29	455.43	1012.72	41.95%	55.03%
2017-07-21	215.78	42.36	202.47	460.61	421.58	882.19	43.96%	52.21%
2017-07-22	331.22	61.96	484.86	878.04	387.75	1265.79	55.22%	69.37%
2017-07-23	281.82	44.13	453.23	779.18	352.57	1131.75	58.17%	68.85%
2017-07-24	313.59	58.29	249.31	621.19	401.35	1022.54	40.13%	60.75%
2017-07-25	265.62	54.74	283.88	604.24	407.58	1011.82	46.98%	59.72%
In total	2892.04	530.26	3873.77	7296.07	4124.77	11420.84	53.09%	63.88%

4. Conclusion

Potential for energy savings in the manufacturing sector lies not only in optimizing production process for energy, but also in developing novel energy monitoring approach [27]. In this paper, an IoT based energy efficiency monitoring system for machining workshop is proposed. To validate the effectiveness and benefits, an industrial application of the proposed system is demonstrated. With the proposed system, potential opportunities for energy efficiency improvement can be identified.

To the authors' knowledge, no paper has proposed an IoT based energy monitoring system for machining workshop like the work presented here. This work compliments the work in [28] that proposed a general framework of energy consumption monitoring system, thereby making the proposed system in this paper more applicable to machining industrial settings. With the application of the proposed system, manufacturers can easily reduce energy consumption and energy cost by effectively managing the machining process. Furthermore, a sustainable reputation of the machining industry will be demonstrated to the public.

This research can be extended in several directions. For instance, the energy efficiency of the machining task is highly depended on the process route and cutting parameters of each operation. With the application of the proposed system, the relationship between energy efficiency of machining task and process route, cutting parameters can be constructed. Better process route and cutting parameter schemes can be obtained by further data mining. Future work also includes monitoring multiple machine tools by using one industrial personal computer to reduce the hardware cost.

Acknowledgements

This work is supported in part by the National Key R&D Program of China (No. 2017YFF0207903), and the National Natural Science Foundation of China (51475059).

References

[1] Cai W, Liu F, Zhou X, Xie J. Fine energy consumption allowance of workpieces in the mechanical manufacturing industry. Energy, 2016;114:623-633.

[2] Gutowski T, Dahmus J, Thiriez A. Electrical energy requirements for manufacturing processes. In Processings of 13th CIRP International Conference on Life Cycle Engineering, 2006.

[3] Wang Q, Liu F, Li C. An integrated method for assessing the energy efficiency of machining workshop. Journal of Cleaner Production,2013; 52(4): 122-133.

[4] Balogun VA, Edem IF, Adekunle AA, Mativenga PT. Specific energy based evaluation of machining efficiency. Journal of Cleaner Production, 2016;116:187-197.

[5] Schudeleit T, Züst S, Wegener K. Methods for evaluation of energy efficiency of machine tools. Energy, 2015;93:1964-1970.

[6] Rajemi MF, Mativenga PT, Aramcharoen A. Sustainable machining: selection of optimum turning conditions based on minimum energy considerations. Journal of Cleaner Production, 2010;18(10):1059-1065.

[7] Negrete CC. Optimization of cutting parameters for minimizing energy consumption in turning of AISI 6061 T6 using Taguchi methodology and ANOVA. Journal of Cleaner Production, 2013; 53:195-203.

[8] Yan JH, Li L. Multi-objective optimization of milling parameters: the trade-offs between energy, production rate and cutting quality. Journal of Cleaner Production, 2013;52:462-471.

[9] Velchev S, Kolev I, Ivanov K, Gechevski S. Empirical models for specific energy consumption and optimization of cutting parameters for minimizing energy consumption during turning. Journal of Cleaner Production, 2014;80: 139-149.

[10] Wang B, Liu Z, Song Q, Wan Y, Shi Z. Proper selection of cutting parameters and cutting tool angle to lower the specific cutting energy during high speed machining of 7050-T7451 aluminum alloy. Journal of Cleaner Production, 2016;129: 292-304.

[11] Li C, Xiao Q, Tang Y, Li L. A method integrating Taguchi, RSM and MOPSO to CNC machining parameters optimization for energy saving. Journal of Cleaner Production, 2016;135: 263-275.

[12] May G, Stahl B, Taisch M, Kiritsis D. Energy management in manufacturing: From literature review to a conceptual framework. Journal of Cleaner Production, 2016.doi: 10.1016/j.jclepro.2016.10.191

[13] Vijayaraghavan A, Dornfeld D. Automated energy monitoring of machine tools. CIRP Annals - Manufacturing Technology, 2010;59(1): 21-24.

[14] Hu S, Liu F, He Y, Hu T. An on-line approach for energy efficiency monitoring of machine tools. Journal of Cleaner Production, 2012;27(6):133–140.

[15] Palasciano C, Bustillo A, Fantini P, Taisch M. A new approach for machine's management: From machine's signal acquisition to energy indexes. Journal of Cleaner Production, 2016;137:1503-1515.

[16] Liu P, Liu F, Qiu H. A novel approach for acquiring the real-time energy efficiency of machine tools. Energy, 2017;121:524-532.

[17] Sun Z, Li L, Dababneh F. Plant-level electricity demand response for combined manufacturing system and HVAC system. Journal of Cleaner Production, 2016;135:1650-1657.

[18] Li L, Li C, Tang Y, Li L. An integrated approach of process planning and cutting parameter optimization for energy-aware CNC machining. Journal of Cleaner Production, 2017.doi: 10.1016/j.jclepro.2017.06.034

[19] Tao F, Wang Y, Zuo Y, Yang H, Zhang M. Internet of Things in product life-cycle energy management. Journal of Industrial Information Integration, 2016;1:26-39.

[20] Mourtzis D, Vlachou E, Milas N, Dimitrakopoulos G. Energy consumption estimation for machining processes based on real-time shop floor monitoring via wireless sensor networks. Procedia CIRP, 2016; 57: 637-642.

[21] Zhong RY, Dai QY, Qu T, Hu GJ, Huang GQ. RFID-enabled real-time manufacturing execution system for mass-customization production. Robotics & Computer Integrated Manufacturing, 2013; 29(2):283-292.

[22] Zhong RY, Xu X, Wang L. IoT-enabled smart factory visibility and traceability using laser-scanners. Procedia Manufacturing, 2017; 10:1-14.

[23] Mourtzis D, Vlachou E. Milas N, Xanthopoulos N. A cloud-based approach for maintenance of machine tools and equipment based on shop-floor monitoring. Procedia CIRP, 2015; 41:655-660.

[24] Mourtzis D, Vlachou E, Milas N. Industrial big data as a result of IoT adoption in manufacturing. Procedia CIRP, 2016; 55: 290-295.

[25] Li C, Chen X, Tang Y, Li L. Selection of optimum parameters in multi-pass face milling for maximum energy efficiency and minimum production cost. Journal of Cleaner Production, 2016;140:1805-1818.

[26] Thakur A, Gangopadhyay S. Dry machining of nickel-based super alloy as a sustainable alternative using TiN/TiAlN coated tool. Journal of Cleaner Production, 2016;129:256-268.

[27] O'Driscoll E, Kelly K, O'Donnell GE. Intelligent energy based status identification as a platform for improvement of machine tool efficiency and effectiveness. Journal of Cleaner Production, 2015;105:184-195.

[28] Shrouf F, Miragliotta G. Energy management based on Internet of Things: practices and framework for adoption in production management. Journal of Cleaner Production, 2016;100:235-246.